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# THE PLENUM OR PROPULSION SYSTEM

OF

# HEATING AND VENTILATION

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# THE PLENUM OR PROPULSION SYSTEM OF HEATING AND VENTILATION

BY

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QUALIFIED BY EXAMINATION AS
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To

W. ROLAND PECK, Esquire
P.P.A.I., F.S.I., F.I.E.A.I.

AS

A TOKEN OF ESTEEM AND RESPECT

FROM HIS OBLIGED FRIEND

THE AUTHOR

# PREFACE

THE present-day practice of Architecture, with its multitude of allied Sciences and Arts, necessarily boasts a very extensive literature, which increases almost daily. This being so, the practitioner is enabled to pursue his never-ending studies, and thereby to keep pace, in a measure, with the giant strides made by Science in the construction and equipment of buildings.

Of late years this advance has probably been greatest in the direction of Sanitation. Health, with its next-of-kin, Comfort, has become with comparative suddenness, a prominent factor in the requirements of the Public. Yet, strange to say, the two Sciences, which, perhaps, most directly influence our health and comfort, have not progressed in any commensurate terms with the other branches of Sanitation; and thus Heating and Ventilation are effected, in the majority of our buildings, by means of fires and windows,—the agencies adopted by the past generations, and which no one will say are wholly satisfactory. Indeed, every architect is aware of the great improvements which have been made in grates and stoves, and also of the numerous inventions in the shape of ventilators, many of which are excellent, but none of these can be said to represent a system in themselves, they are designed only to supplement fenestral ventilation. These improvements on the one hand and inventions on the other, by their very existence, go to prove that the old methods leave much to be desired.

This halt in the general advance exists in the practice rather than in the theory, for science and invention have produced more effectual modes of Warming and Ventilation, which have only to be more widely known to be more generally appreciated and more generally adopted.

Unfortunately the theory of Ventilation is a complex study, involving several diverse sciences, such as Chemistry, Pneumatics, Heat, Electricity, and Steam and Mechanical Engineering,—in fact, an education of itself sufficient to form an independent profession. There seems to be an unaccountable dearth of published information on the subject of Modern Ventilation as such. This renders it necessary for the student to study the various sciences, and to build up all his theories for himself from fundamental data. It is, of course, impossible for the average busy architect to add such a course to his already extensive curriculum. On the other hand, he objects to blindly trust another man with such an important part of his work, and, moreover, Mechanical Ventilation naturally appears to him of the nature of an unknown quantity in his calculations ; so he very logically prefers to follow in the footsteps of his forefathers, and place his trust in the elements. At worst, the disadvantages attendant upon ventilating by the window and heating by fires are known to him.

By writing a short practical account of the principles of Plenum Ventilation, I have herein attempted, in some small degree, to bridge the gap between expert knowledge and no knowledge at all, which exists in the literature relating to this important branch of sanitation.

To include in one brief volume all the information necessary to enable an architect to design a propulsion system would be as impossible as it would be for him to afford the time to study it if written ; but he will find sufficient in the following pages to place him in a position to criticise a scheme, and while he must of necessity leave the details to the expert, yet he will be enabled to superintend the structural part of the work.

Upon the suggestion of several professional friends I have included a few hints which may be of assistance in inspecting and testing the work when completed ; and have also added an outline specification to serve as a guide for a Plenum installation.

HAROLD GRIFFITHS.

8, CRAIG,S COURT, WHITEHALL, S.W.
*January* 1905.

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# THE PLENUM OR PROPULSION SYSTEM

OF

# HEATING AND VENTILATION

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## CHAPTER I

### *INTRODUCTION*

THE two sciences, "Ventilation" and "Heating," are so closely related to each other that the one cannot be satisfactorily dealt with to the neglect of the other; and although, theoretically, they may sometimes be regarded independently for the sake of convenience, yet, in practical work, temperature and atmospheric circulation act and react on each other to such an extent that it is impossible to divorce them in actual treatment.

Ventilation as applied to a building may be very simply defined as "change of atmosphere." In the simplicity of the definition the fact must not be lost sight of, that change of atmosphere involves a dual process,—the admission of fresh air, and the expulsion or extraction of the stale or vitiated air.

With regard to heating it must also be remembered that, as an operation in connection with buildings, the term must be used (for lack of a better) to indicate, not only the operation of raising the temperature, but that of reduction.

It is obvious that it is not sufficient to merely change the air in a room, and to warm or cool the apartment, without regard to more definite conditions. For example, what might reasonably be considered as ample ventilation for the lending department of a public library would be wholly inadequate for a crowded theatre or lecture-hall. The question of "quantity," or "degree," must therefore enter into the calculation. Nor is it sufficient to assume that provision may be made for a constant amount of atmospheric change in an apartment, for the quantity of ventilation necessary will vary from time to time, according to the requirements of the occupants. In short, the amount of the ventilation must be under control, to be increased or decreased at will.

Another requirement of sound ventilation is, the change of air must take place equally throughout the space treated ; there must be no sheltered nooks nor stagnant corners, but the fresh air must search out every part of the apartment and, by its presence, expel the vitiated.

Not only must the quantity of air admitted be under control, but its velocity also. Should the movement be sluggish, its momentum will be insufficient to carry it through its course over the more protected places. On the other hand, should there be anything approaching a violent inrush, the result would be a breezy commotion in the atmosphere, which, to say the least, would be inconvenient, and discomforting, more or less, according to the position of the inlets.

Should the currents be of a different temperature to that of the air already occupying the building,—either higher or lower,—they constitute those bugbears of Ventilation—draughts. It is noteworthy that the atmospheric movement does not in itself cause draught, unless there is an appreciable difference in the temperature of the air admitted and that already in occupation. When this difference exists, it therefore follows that the incoming air should move slowly and gently, should be admitted and directed in such a manner as not to come into contact with the occupants of the room until it has dispersed and lost a large amount of its initial velocity, and it should also be admitted in such quantities as to thoroughly do its work of Ventilation, although low in velocity.

Having so far dealt with the quantity of fresh air admitted, it would be well to briefly consider its quality. It should be sufficiently humid and as clean as possible—that is to say, free from suspended particles such as soot. The architect, whose drawing office happens to be in London or any of the large cities, will particularly appreciate this, as frequently he closes his windows, preferring to work without Ventilation to opening them and admitting the air laden with "blacks." At the present stage of the science of Ventilation, it may be regarded as too idealistic to say that the incoming atmosphere should also be free from flies and other insects. Yet it cannot be denied that it would be a boon to have plenty of fresh air in the summer months, free from insects as well as from impurities.

The improper introduction of the fresh air is not the only cause of atmospheric currents and draughts, they are often the effect of an unwise disposition of stoves (or other warming apparatus) with regard to the position of the ventilating openings. In fact, in all cases where the temperature of air is raised after its admission, these currents of various temperatures are more or less unavoidable. Nevertheless, this forms a possible defect in the warming scheme, which should be so arranged as in no way to detract from the efficiency of the Ventilation.

Another way in which the warming often proves detrimental to Ventilation is in chemically changing the natural constituents of the air. This is particularly the case when the heating is effected by direct combustion, whereby a large proportion of the fresh air supply is nullified.

As in Ventilation, so in Warming, the operation should be under complete control, and it should be an easy matter to raise or lower the temperature of an apartment to any degree desired (within reasonable limits).

It may be logically deduced from this, that an even temperature must permeate the whole of the area treated.

To summarise it may be stated axiomatically that the requirements of ideal Ventilation and Warming are:—

1. Fresh air must be admitted and the foul expelled.
2. The rate of admission must be under control,
    (*a*) As regards quantity,
    (*b*) As regards velocity.
3. The change of air must take place equally throughout the whole of the apartment treated.
4. There must be no windy currents or draughts.
5. The air admitted must be humid and clean.
6. The fresh atmosphere must not be allowed to undergo chemical changes by its contact with the heating apparatus.
7. The temperature must be under complete control, and must be uniform throughout the space to be heated.

Broadly, there are two methods by which these requirements are met, with results more or less satisfactory. These are—Natural Ventilation and Mechanical Ventilation.

Natural Ventilation is change of air effected by means of the natural dynamic forces of the atmosphere, without recourse to mechanical agencies.

Mechanical Ventilation is change of air effected by means of mechanical power.

Unfortunately for the latter, there is a certain charm attaching to anything existing under the appellation of " Natural," which, in the absence of some amount of consideration, is liable to generate prejudice. " Let Nature do her work " is a sentence one often uses, without stopping to question whether the work is Nature's work at all. The maxim is sometimes used with reference to Ventilation, incongruous as it is when applied to anything so purely artificial as a building. In fact, Man is so artificial an animal—so unnatural—and has been so for so many ages, that it has long since become natural for him to be unnatural.

Let the question of the naturalness of Natural Ventilation remain in abeyance, at least till those matters have been examined which do not lie so much on the surface as the mere name.

In Natural Ventilation the air is admitted through an opening in the external walls—usually the windows. Three forces must be considered in effecting the atmospheric change under this system ; firstly, the wind, which for all practical purposes may be regarded as a horizontal force tending to impel the air into the building ; secondly, a vertically upward force, due to the expansion of the air (if warmed) on its entrance, and its consequent loss of weight and its tendency to rise ; thirdly, the converse effect of the contraction of the atmosphere (if cooled), which represents a vertically downward force.

The last two forces, though important factors, are almost wholly dependent on circumstances. For example, on a cold winter's day the tendency of the air on its entrance into a warm building would be to fall, and should the inlets be high enough, this would obviously in turn tend to draw more air into the building. But on a hot sunny day, when the temperature in the building is lower than that outside, the effect would be the reverse. And between these two extremes comes the mean, where the vertical forces (up or down) exist in a less and less degree until a state of equilibrium obtains. These vertical forces therefore, though of undeniable importance, are of such a variable nature that they are quite unreliable, and are generally neglected altogether.

The direct action of the wind tends, of course, to drive the air into the building. But there is another action, which, though slight in comparison, must not be overlooked. The wind rarifies the air on the sheltered side of the building to some extent, and tends in a small degree to extract the air from that side, which is not otherwise affected. This extraction is quite inconsiderable, except during a wind of high velocity, and it is never relied upon as forming a part of any mode of Natural Ventilation.

Wind pressure, then, must be regarded as the principal motive for the introduction of fresh air, and the expulsion of the vitiated atmosphere must be dependent upon the pressure caused by the incoming.

Natural Ventilation is often augmented by extracts of more or less mechanical design ; but, whether such be used or not, it is obviously almost a necessity that both impulsion and expulsion must take place through an external wall or a roof.

In most rooms, even in a large public building, owing to the exigencies of planning, only one external wall is available for the purpose of ventilation. In such cases, as the conditions regarding wind pressure extend practically equally over a wall, the openings in it cannot be taken to be at the same time entrances and exits for the air; and since means of egress are as essential to Ventilation as the aperture for ingress, the operation of expulsion depends on such accidents as the existence of chimney flues, or the opening of an internal door. The influence of the latter on Ventilation is a matter of common observation; and yet the driving of the vitiated air from one part of the building to another cannot strictly be called Ventilation at all. Unfortunately, this is very often unavoidable, particularly in large buildings divided into a number of rooms, in which case the plan will not admit of the majority of the rooms being cross-ventilated.

The quantity of the Ventilation affected by the Natural system is only partially under control, that is to say, the entrance of the fresh air can be regulated by the opening or closing of windows, or such other means as may be adopted for its admission. The amount of air admitted in a given time is measured by the area of the outlet opening multiplied by the wind velocity resolved at right angles to the plane of the opening, so that, inasmuch as the size of the opening can be varied to a certain extent, the amount of air admitted is under control; but, on the other hand, as the entrance of fresh air is due to the amount of the wind pressure and its direction, this cannot be regulated. In other words, if the wind be directed against the openings, and, should its velocity be such as to supply more air than is required, windows, etc., can be closed or partially closed, and the Ventilation regulated to the required degree; but, should the velocity of the wind be too low, or in such a direction as not to be against the openings, then it is clear that no opening of the windows will induce the air to enter the apartment required to be ventilated, and Ventilation, as such, ceases.

Again, the closing or opening of the apertures regulates the *area* of the volume of fresh air. The velocity is as uncontrollable as the wind (which it really is), so that:

$$\left.\begin{array}{c}\text{The amount of}\\\text{air admitted}\end{array}\right\} = \begin{array}{c}\text{(Area of opening, a}\\\text{controllable quantity)}\end{array} \times \begin{array}{c}\text{(Resolved atmospheric}\\\text{velocity, an uncon-}\\\text{trollable quantity)}\end{array}$$
$$= \text{A partially controllable quantity.}$$

It is self-evident that, were the factors reversed and the atmospheric velocity (and its direction) controllable, the area of the opening might be constant, and the amount of Ventilation would be under perfect command. In Natural Ventilation this is of course impossible; but in Mechanical Ventilation such an arrangement becomes quite practicable.

This entire lack of control over the velocity (and direction) of the incoming air must, of necessity, result at times in more or less violent atmospheric currents in the area ventilated. Apart from the inconvenience of these breezes passing through the apartment, discomforting to the occupants and giving motion to all the lighter articles in the place, they are attended by a more detrimental attribute. Instead of the air passing into the building with just sufficient velocity to allow of its finding its exit after spreading itself over the whole of the space to be ventilated, and then being expelled by virtue of the pressure of air sustained in the apartment, it passes through in a rapid stream direct, or nearly so, from the entrance to its exit. Here and there it may meet with obstacles causing reflection and eddies, but under the conditions it must certainly leave stagnant places.*

When these air currents are of a different temperature to that already existing in the building, they become draughts. Draughtiness, if not the greatest fault possible in any mode of Ventilation, is at any rate the one most readily detected and most generally complained of. In fact, one meets people daily who have such a dread of draughts that they prefer stagnant air, no matter how vitiated. In a short journey in a railway train, should there be six or eight persons in the compartment, and one of that number either feels, or fancies he feels a draught, a complaint is made, both windows become closed, and after a while the air is abominable, and possibly impregnated with disease. At most of our theatres, as soon as the performance commences, all doors are closed. After the first act, the doors are opened, and the inrush of cold air into the warm and vitiated building almost carries one along with it. Again, in many wholesale houses and workrooms, there is no pretence whatever of ventilation.*

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* Perhaps the best example of Natural Ventilation is afforded by a model hospital ward. This building is generally planned especially with a view to an efficient atmospheric change, and consists of a long rectangular room with ample windows (and possibly other openings) along both of the long walls. From whatever quarter the wind may blow it is nearly certain to play directly or obliquely on one side, in which case the windows on that side become inlets, and those on the opposite side are outlets, thus ensuring (when there is any wind at all) a good cross-ventilation or "blow-through." The beds usually stand singly or in couples against the piers between the windows, along both sides of the ward, leaving the end or corner bed each with a window on one side only, and the end wall of the ward on the other side. Where this arrangement of plan obtains it is noteworthy that, generally, the particular beds in question are regarded as the "unlucky beds," and it is startling how often the mortality record of the establishment grimly shows the reason of their evil reputation.

To filter the air or to cleanse it in any way as it passes through a window is of course an impossibility. In country or sea-side places such a course is quite unnecessary; but in our large towns and cities, particularly those in manufacturing districts, an operation of this sort is a *sine qua non* of efficient ventilation. And when one has to inhale an atmosphere laden with impure dust and soot (if not with anything worse), one is apt to question the naturalness of Natural Ventilation.

It is just as impossible to humidify the air, which is a great detraction from Natural Ventilation, when the atmosphere has to be warmed after its entrance.

When the temperature is raised by combustion, other chemical changes take place, which are still more detrimental to ventilation than the drying up of the natural moisture. The heating by stove or fireplace is also essentially local, causing a variety of temperatures in different parts of the apartment, running through the whole gamut from the cold air where it is admitted at the inlets to the extreme heat as it is consumed in the fire.

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* In the counting-house of a London firm, which recently came under the notice of the writer, although the office was closely packed with clerks, even the windows had been pasted up with paper to prevent any air finding its way into the room, the only possible change of air being through the doors when opened from the warehouse adjacent. One marvels that human life can be supported by such an atmosphere as must exist towards evening, when the gas has been burning all day, and from forty to fifty clerks occupying the room. Under such circumstances what a Godsend a propulsion system of heating and ventilation would be—where warm filtered and humidified air could be constantly delivered into the room without causing the slightest draught. Is it not probable such a system would add years to the lives of those occupying such premises?

This localisation of the heated area is as great an offender, as regards the creation of wind currents and draughts, as the wind. The warm air expands and rises by virtue of its comparative lightness, partly in the room and a large proportion rushes up the flue and so makes its exit, thus converting the chimney into an extract, far too powerful in comparison to the area of the opening. The cold air rushes in to fill the space, which would otherwise be a vacuum, and hence the draughts of the winter fireside. The only means of amelioration lies in closing the air inlets.

But by so doing the one evil is merely changed for another. It is just when the oxygen is being consumed by the combustion that a plentiful supply of fresh air is most required, and for the reason stated, this is just when Ventilation is reduced to a minimum.

When hot water, or steam pipes and coils are used, the heating is certainly more distributed, though the temperature is still far from being uniform, and consequently the deleterious effects observable in heating by direct combustion still exist, though in a modified degree.

To say that the temperature of a room is under control is equivalent to saying that it is possible to raise or lower the temperature at will, to any given degree within reason. This is, of course, out of the question where different temperatures exist in different parts of the room at the same time.

When heating is effected by fires or stoves the method adopted to raise or lower the temperature is the somewhat primitive one of stoking. Steam or hot water pipes admit of more efficient control, of course, though the same objection rests to some extent with them, that the temperature of the room is not uniform at all parts at the same time.

To summarise, then; the defects in Natural Ventilation and the corresponding Heating are:—

1. The fresh air is not always obtainable, and in many cases it is impossible to provide adequately for the expulsion of the vitiated air.
2. The rate of admission as regards quantity is only partially under control, and as regards velocity it is quite uncontrollable.
3. At times the change of air cannot take place equally throughout the whole of the apartment treated.
4. Natural Ventilation is subject to windy currents and draughts.
5. The air admitted cannot be cleansed, nor satisfactorily humidified.
6. When the air is heated by combustion it undergoes deleterious chemical changes.
7. The temperature cannot be under complete control, since it is not uniform.

Such a formidable list of indictments may appear startling when tabulated as above. But, nevertheless, there is nothing new in these objections to the old mode of ventilation and heating; they have been fully recognised in the past. "Ventilation without draught" has been the quest of all who have exercised their inventions in the science. Now the words have become a stock phrase and the idea is almost regarded as Utopian. Many contrivances have been employed to effect the object, but windows and doors are still draughty.

Vessels of water are kept boiling on stoves with the object of surcharging the air with moisture. Experience proves that by their use the heated atmosphere becomes more breathable, but they are all inadequate to totally counteract the drying properties of the warm air.

It is by reason of their length of service that we tolerate the window and the stove so easily. The attendant evils have been endured so long, that one scarcely regards them as such.

But the greatest difficulty in the way of satisfactory Natural Ventilation remains to be dealt with. It exists in the fact that vitiated air is generally heavier than pure air, and therefore, owing to its weight sinks, while the pure air rises above it. So that, if any vitiated air exists in a room, it is not suspended in proximity to the ceiling (where it would not be harmful), but it forms the lower strata of the atmosphere, where it is breathed over and over again by the occupants of the room.

What is necessary to make Ventilation and Warming successful and reliable is to have the wind under control. If this could be, and at the same time if it were possible to provide openings for the exit of the vitiated air wherever required, irrespective of the accident of plan ; then it would be possible to admit air at any velocity required, and without any closing or opening of windows ; it would enter in just the necessary quantities, moving in the required direction—neither too sluggishly or in inconvenient currents—but finding its way by virtue of the pressure of the incoming air, to its allotted exits. If, further, the possibility to govern the weather be added to the hypothesis, still more would be accomplished. Were it necessary for a room to be warm, instead of admitting cold air and warming it in certain places, with the effect previously described, a gentle summer breeze could be induced—in other words, as long as the temperature were constant, the temperature of the incoming air would practically be the same as that already occupying the room, and, even though it moved with some celerity, it would be devoid of draughts.

Moreover, since the air, which would perform the operation of ventilation, would also effect that of warming, the one would be as uniform and distributed as the other, and under as complete control.

It only remains to assume that the air can be cleansed before it enters the room, and, if too dry, humidified to the necessary degree of moisture, and then we have imagined a form of Ventilation and Warming approaching as near to perfection as the present knowledge of our requirement will permit.

But the assumption of such hypotheses renders the argument founded upon them merely ideal, chimerical, impossible. As applied to Natural Ventilation it is so. It nevertheless represents the objects of the mechanical methods and also the means of obtaining them.

Though the control of the natural elements is beyond human power, yet the air can be moved by mechanical means at any velocity, in any direction, and in any volume required. This is the hub of all the system of Plenum Ventilation.

By *Plenum* or *Propulsion* is meant the system of constantly pressing or forcing air into a building, and thereby changing the whole of the atmosphere continually, thoroughly, and regularly.

This mode of Heating and Ventilation consists of propelling, by means of mechanical power, screened and humidified air (heated when necessary), along horizontal ducts, through vertical flues, discharging it into rooms, and after circulating it throughout the same, passing it through extract ventilators to the open air.

The air within a building ventilated upon this system is necessarily of greater density than that under natural circumstances—in other words, it is under increased pressure—but so slightly as not to be noticeable. This being the case, the air endeavours to escape, by means other than the expulsion gratings provided for the purpose, and it is essential that all joinery to windows and doors should "fit"; otherwise, if any considerable amount of air be allowed to escape, the proper and efficient circulation throughout the rooms would be impeded. The nearer the amount of air released at the extracts is to the amount of air delivered, the more thorough will be the circulation.

As the air is under pressure, the opening of a window would be sufficient to allow an amount of the intake air to escape. While the apparatus is working and the rooms are under pressure, no air will enter the building by an open window—except perhaps while a gale is blowing directly upon the window with a wind pressure greater than the atmospheric pressure of the internal air.

Supposing a building with the propulsion installation had the whole of the windows opened, the effect would be that the air forced into the various rooms merely passed from the inlet to the exterior, without effecting any other change or circulation throughout the room; and under such circumstances, little or no air would find its way to the extract gratings. *Windows and doors should therefore be kept closed.* But, as doors have of necessity to be opened and closed, the installation should be so calculated as to make allowances, so that this almost unavoidable escape may not interfere with the proper circulation of the remainder of the building.

As no air from the exterior finds its way into the building during the time that the installation is working, the consequence is, little or no dust enters either. It is surprising how clean a building keeps which is operated upon by propulsion, provided the air be properly cleansed before it enters the rooms. The majority of the dust in the rooms is that brought in from the boots of those using the premises. Even when sweeping, the light particles of dust never rise to a height of more than three feet from the floor, but are carried up to the extract flues, and very little else remains. It is, of course, necessary to keep the apparatus working while the sweeping is in operation. Should the building operated upon be situated adjacent to a manufactory, workshop, railway, or where machinery is in constant motion, as the windows will remain closed, little or no inconvenience arises; but, in the case of an ordinary ventilated building, it would altogether prevent the windows being opened with any degree of comfort to the occupants.

The risk of a building taking fire is reduced to a minimum, and this fact should correspondingly reduce the Insurance rates, where a building is heated and ventilated by this process.

Owing to the air being brought into contact with water, the temperature is reduced, and during the hot sultry months the temperature of a building thus operated upon is many degrees lower than that of the external air in the shade. It can be further reduced by passing the air through a layer of ice, but this is seldom necessary.

It also has the advantage of admitting scarcely any fog into the building, even when the fog is dense in the streets.

The air should always be taken from a height of at least ten feet above the ground level. This prevents the propellers drawing the dust from the surface on to the air purifier. In some of the provincial installations the air is taken from a specially designed tower of architectural treatment, rising to a considerable height.

It is thought by many interested in Plenum Ventilation, that the whole of the working plant should be duplicated. This would entail considerable additional outlay; for not only would it be necessary under such circumstances to supply two boilers, two engines or motors, and a double set of propellers, etc., but the basement to contain them would have to be larger in proportion, and the necessary connections would have to be arranged so as to connect up the duplicate plant in case of emergency. An installation can always be relied upon, if it be well thought out, and proportioned upon a practical and scientific basis in all its working parts, and provided, also, that it be in use only for a given number of hours per day—that is, allowing a period of rest during the twenty-four hours. In such cases as churches, workshops, public buildings, and schools, a duplicate plant appears to be unnecessary, because during the hours that the apparatus is at rest, the ordinary renewals and repairs could be effected, and these rarely consist of anything beyond providing new, or adjusting or rebushing the existing, bearings of the engine or motor, or the repairing of the main driving strap. With the many installations of which the writer has had experience, and each working from eight to fourteen hours per day—there has hardly been a case in which the occupants of the buildings have been inconvenienced in an intermittent run, extending in some instances over a period of nine years.

But where the installation has to run night and day from year to year, in such cases as asylums and hospitals, it becomes absolutely necessary to duplicate the working parts, because there is no period of rest, when even the most casual repairs or renewals can be effected.

Where provision has been made to supply a duplicate plant, it is recommended that each plant be worked alternately for, say, a week at a time (and in the case of a boiler a month at a time). Where one plant is continually in use, and there is a sudden breakdown, it may perhaps happen (unless the duplicate plant is being worked alternately) that there is something out of order with it at the very moment the plant is required to be put into operation, and so the object of providing a duplicate plant is defeated. Both, therefore, should be kept in actual working order, and as soon as any parts are discovered to be defective the needful repairs should be effected as speedily as possible.

It has been stated that one great objection to Plenum Ventilation is the unvarying temperature of the air within the buildings operated upon. In reality, it is more difficult for a plenum engineer to maintain a constant temperature night and day during winter and summer, than to effect variations in the temperature.

By passing air in summer through an ice screen it is easy to maintain a temperature within a building 20° to 30° lower than that of the exterior air, and in winter the air can be delivered as low as the external air on a frosty day by omitting to use the heating batteries, or can be raised in temperature according to the power of the battery provided, to any heat required within reason.

Further, the temperature can either be maintained or varied within a few minutes, at the will of the person occupying any individual room, without influencing in the slightest degree the remaining rooms in the same building, or can even be pulsated automatically warmer and cooler, if thought desirable.

One of the greatest advantages of Plenum Ventilation is the perfect varying or unvarying control which a well-designed installation possesses.

Again Plenum Ventilation is frequently condemned, because, it is stated that, by bringing the air into a room at or near the ceiling, and expelling it at the floor line, "it is acting against nature." This is incorrect—carbonic acid gas and other constituents of vitiated air, as soon as cooled, are heavier than natural pure air, and consequently have a tendency to fall. Bringing the pure air down from the upper part of the room, and extracting it at the floor level, and so preventing these expired gases rising, appears to be the natural system of ventilation. Moreover, by this means, the pure air from the upper part of the room reaches the nostrils before it becomes contaminated by passing over the body, so that the lungs receive the purest air in the room.

In bringing in the air near the top of the room, and extracting it at the bottom, by the time it reaches the heads of the occupants, it is so dispersed and diffused that it has lost most of its velocity, and passes the body with so slow a movement that no draught is perceptible.

There is yet another advantage with the so-called downward ventilation. The dust, always lying on the floor, is prevented from reaching the nostrils when disturbed and set in motion by people continually walking about, as it is prevented from rising by the downward action of the air.

When gas is in use, an opening should be provided at the ceiling level, and connected to the floor flue so as to take away the burnt air, and prevent its being brought down near the floor to be breathed by the occupants. This is not difficult to accomplish in practice, because in the combustion of gas, great heat is generated, which rises and keeps at or near the ceiling, and is therefore easily carried off by the flue provided for the purpose.

Some advocates of Plenum Ventilation assert that the changes of the air within the rooms should be regulated from the outlets, and not by the inlets. It really matters little whether the air be controlled at the outlet or inlet, so long as the prescribed changes per hour be delivered, but nothing could be more convenient for regulating the flow of the air than a horizontal damper fixed at the base of each vertical intake flue, and under the sole control of the attendant in charge.

# CHAPTER II

## *POSITION OF MECHANICAL APPARATUS*

IT is desirable, where practicable, to fix the engine or motor, pumps, boilers, propellers, and such like apparatus, in a separate chamber outside the main walls of the building to be installed, in order to avoid, as far as possible, vibration in the building. The reason for this will be readily understood. The air, in its passage through the ducts and flues, is a ready carrier of sound—indeed it is quite an easy matter for the occupants of the rooms to distinctly hear ordinary conversation which is being carried on in the ducts, although the rooms operated upon may be several hundred feet from the speaker. No matter how admirably the installation be arranged, where machinery is in constant motion there is sure to be vibration more or less: even the propellers are conveyors of vibration from the action of the straps rotating them.*

When the incoming air is heated by the batteries within the ducts, immediately before it ascends the vertical flues, and not close to the filtering screen, as in some instances, the mechanical portion of the installation may be laid as far from the building as convenient. But it must be borne in mind that the further away the machinery is placed, the greater the cost will be, because the ducts conveying the air must necessarily be increased in length.

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* Some little time since, the writer was consulted in regard to the noise made by a steam engine working a propulsion scheme in a school. The engine, which made 240 revolutions per minute, or 4 revolutions per second, was fixed in a concrete bed immediately under a classroom occupied by sixty children. The vibration was such that it rendered not only the room over utterly useless for scholastic purposes, but also the adjacent classrooms. The steam engine was removed, a gas engine substituted, and a false ceiling provided, filled with 2 in. of sand, with highly satisfactory results.

There is another advantage in placing the mechanical parts in a separate building. It permits of the air intake being placed the maximum distance from the exhaust air extracts, thus preventing the possible readmission of the vitiated air, which, when expelled from the building, suddenly cools and falls ; and if too near the intake, would be liable to be conveyed by wind currents back to the air intake. In that case the same air would consequently be re-used over and over again.

# CHAPTER III

## *PROPELLING POWER*

THERE are chiefly three methods in use for supplying the driving power—namely, by steam engine, by gas engine, and by electric motor.

In the North of England steam engines are generally used, but probably there is no engine so noiseless and so serviceable for a propulsion installation as a gas engine. In addition to creating more vibration, steam engines have a double disadvantage. They cannot be started until steam is up, (generally about three hours), and in order to work them effectually, a greater pressure of steam has to be maintained than is required in cases where steam is generated solely for the purpose of heating the batteries.

Then again, during the summer months, when the heating batteries are not required, the boiler must still be fired, or else a subsidiary boiler provided for working the engine. Thus the initial outlay, and also the cost of maintenance, is greater; and during the winter months the subsidiary boiler is lying idle and rusting away.

With a gas engine, its first cost compares very favourably with a steam engine of similar brake power, and it has the advantage of being worked by an unskilled hand; it is always ready the moment it is required, and as soon as the engine is stopped, the expense ceases; and, further, the cost of the wear and tear of a gas engine is less than that of a steam engine.

In laying down a propulsion installation, it is as well to supply an engine of ample brake power for its purpose. An engine is a somewhat costly article, and rises very rapidly in price as the brake or effective power increases. Thus, a gas engine of 4 brake power will cost about 20 per cent. less than a gas engine of 5 brake power—so there is a tendency among propulsion engineers to cut the engine power a little too fine, with the result that the engine becomes overstrained. Although an engine may actually perform its work, yet it should be of such brake power as to do so with ease, so as to obviate any overheating of its bearings, etc., otherwise constant repairs will be found necessary, vibration increased, and the life of the engine materially shortened.

Another important point to be considered is the speed at which the engine should run. For economical work, the engine should make the number of revolutions per minute as described by the manufacturers. Thus an 8 brake engine should make about 220 revolutions per minute, and a 16 brake about 190 revolutions per minute. Should an engine make a less number of revolutions, it is not running economically, and should it be set up to make an increased number of revolutions, it will soon tear itself to pieces. Propulsion engineers appear to often utterly disregard the manufacturers' instructions in this respect, and to prefer to adapt the speed of their engines to the amount of air required to be delivered, instead of adjusting the gear of the propellers to effect this purpose.

When an engine is supplied, it is advisable that it be fixed upon a thin block of stone or cement concrete, overlying a double crossed row of stout timber baulks or railway sleepers. This very materially minimises the vibration, and is preferable to laying the concrete or bedding stone directly on the ground or partly on the ground and the foundations of the building, as in some instances has been carried out.

Gas engines necessarily run at a somewhat high velocity, and, in order to keep them cool, water is required to constantly circulate through the jacket of the cylinders. For this purpose, tanks are provided by the gas engineers; but they are seldom of sufficient capacity for the purpose. When an engine runs for, say, ten consecutive hours, unless there is a sufficiency of water, it would, after a few hours, almost boil. To obviate this, cold water is allowed to constantly run into the tank, and a corresponding amount flows away. This is a wasteful process, and in a year would consume a large quantity of water. A tank, or series of tanks, connected to each other, having a total capacity of about two thousand gallons, would be a suitable content for a 16 brake engine. With this capacity of water, no running to waste would be necessary, as, by the time the water from the cylinder had passed through each compartment, and again returned to the engine, it would be quite cool enough for the more effective running of the engine.*

By far the most preferable power is the electric motor. It is not in every case that such a power can be installed, on account of the electric cables not having been laid in the street; but where electricity is available there need be no hesitation in supplying a motor. There is no objectionable odour as from a gas engine exhaust, it revolves at a high speed, and vibration is hardly perceptible, and it takes up but little room. Electric motors give the utmost satisfaction, and they, like the gas engine, can be worked by an unskilled hand.

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* Where such a tank was provided by the writer for a 16 brake engine, only a few gallons of additional water are required for a year's work.

# CHAPTER IV

## *BOILERS*

FEW architects would care to take the responsibility of designing their own boilers, but a few notes on their selection may prove useful.

There are many types of boilers in use in various parts of the country, but for long wear and few or no repairs, a "Lancashire" or a "Cornish" steel boiler appears to be the most suitable for propulsion work. The half-tubular, and multi-tubular boilers of various makes, have the advantage of being put together in sections, and also of generating steam very rapidly, but they will be found to be not nearly so durable as a boiler of the "Lancashire" or "Cornish" type.

Where a gas engine or electric motor is supplied, a boiler is required only for the purpose of generating steam for the heating batteries. But in many instances they have also to work a steam engine. In the former instance, a few pounds pressure of steam only is required, in the latter, the necessary pressure varies from 40 lb. to 80 lb.

## CHAPTER V

### *PROPELLERS*

THE air has to be forced into the building by means of fans or propellers. There are many types of propellers, some comparatively useless, others very powerful.*

There are several open and adjustable bladed propellers working in the Midlands, but the result is not nearly so satisfactory as where a straight-through volume fan is provided ; these latter deliver a greater quantity of air, and are more reliable.

The size and number of the propellers necessary for an installation are a matter of calculation, which therefore lie in the province of the engineer, rather than that of the architect, and need not be gone into here.

There is much diversity of opinion, as to the number of revolutions per minute a propeller should make. Some propulsion experts run them at the same velocity as the engine, while others again at double the velocity. It is economical to get as much work out of a propeller as practicable, but it is easy to overdo this. From two hundred and fifty to two hundred and eighty revolutions per minute should be the maximum velocity, except where silence is not required within the building, as in the case of drying rooms. If this speed be exceeded, there will be a perceptible buzz, and this should not be in any building where quietness is a necessity. At the same time the propellers should be making such velocity as to create a pressure sufficient to thoroughly circulate the air in the rooms, and to effectually displace all vitiated air, and assist in forcing the used air through the extract flues.

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* Upon having to report and advise in regard to a building where there were complaints of a scarcity of air, the writer found there were two propellers, each six feet six inches in diameter, but the blades had been adjusted at such an angle that, what little air was thrown off the extremity of the blades was sucked back through the central part of the propeller again, the fans thus forming themselves into air *churns* instead of air *propellers.* After they had been removed and new pressure propellers substituted, there were no further complaints of scarcity of air.

It is advisable to fix the propellers so as to drive the air directly down the length of the main duct—not, as some propulsion experts fix them, within a few feet of a blank wall, thus causing a proportion of the air to react on the propeller, and thereby placing additional work on the fan.

The propeller should also be fixed on the building side of the air screens, as it is much easier to suck or pull air, so to speak, than to push or drive it.

Each propeller should be fitted with a high- and a low-gear pulley, to allow of the strap of the engine being slipped to either, without altering the speed of the engine. This is necessary where in summer a more frequent change of air is desired, than during the winter months.

# CHAPTER VI

## *AIR PURIFIERS AND HUMIDIFIERS*

THE method of purifying and humidifying the air (that is, removing soots and other impurities and deleterious substances, and giving to the air that degree of moistness necessary for health, before its delivery into the various rooms) is a matter which has seriously taxed the abilities of propulsion experts.

There is no difficulty in finding a material arranged as a screen, which will effectually remove nearly all of the suspended impurities in the air; but a great difficulty presents itself when the suspended particles deposited upon the screen require to be rapidly removed, so as to keep the material of which the screen is composed sweet and clean, and entirely free from sooty odour, in order that the additional air, constantly being pulled through the screen by the propeller, shall not be contaminated by the already deposited residuum.

It is surprising to see the little heap of impurities which are prevented from entering the building by being caught upon the screen, in one day's work in any London propulsion system. It would be impossible to give the exact amount, as they are difficult to collect, being caught up over a considerable area, but they would approximate to nearly half a cubic foot. If this amount of sooty matter were not arrested, it would be distributed in the various rooms, and would prove very inconvenient and more than objectionable to the occupants of the building.

To effectually exclude the many impurities, various means have been adopted; but several of them have proved failures.

In the earlier days of propulsion, little attention was paid to this part of the work; indeed, at the present time the installations in the North, and also in the Midlands, appear to be behind London in their air purifiers. There is some excuse for this in the fact that, in many of the outskirts of the towns in the districts alluded to, the air is freer from suspended impurities than in London.

Generally speaking, the thicker or denser a screen, the more effectual will be the result; but at the same time it must not be overlooked that, with a thick or dense screen, the propellers have much more work in pulling the air through, consequently additional cost will be incurred in running the apparatus.

There are six kinds of screens generally employed in various parts of the country, for the purpose of arresting the impurities in the air. These are:

(*a*) The canvas screen.
(*b*) The coke screen.
(*c*) The fixed fibre screen.
(*d*) The revolving fibre screen.
(*e*) The cylindrical revolving screen.
(*f*) The mist screen.

(*a*) *The Canvas Screen.*—This consists of coarse canvas, stretched on a fir framing, and of such a texture as to allow the air to pass through, thereby screening the suspended matter from the atmosphere. In some cases it is supplied with water to moisten it; but it is neither very durable nor efficacious, nor is it held in general favour.

(*b*) *The Coke Screen.*—This screen consists of a double iron frame about six inches thick, covered on both sides, and top, with wire, and the space filled in with broken coke of various sizes.

In some cases water is laid on at the top by means of a sparge pipe. This keeps the coke damp, and so creates a better lodgment for the suspended particles in the air.

This screen is also unsatisfactory. If the coke be packed sufficiently close to arrest the impurities, it becomes so dense that the propellers cannot pull the air through in sufficient quantities, and if the coke be loosely packed, the air passes freely through the interstices, carrying the impurities with it, thereby rendering the screen useless.

(*c*) *The Fixed Fibre Screen.*—This class of screen is composed of thickly hanging fibre, plaited horizontally at intervals, and fixed vertically to fir rails at top and bottom. At the top a sparge pipe discharges water at intervals down its surface, so keeping it wet.

It must be admitted that it would be almost impossible for any large proportion of the suspended matter in the air to pass this screen; but it possesses the great disadvantage of accumulating soots, etc., which (although the screen be periodically washed with a hose and brush), can never be entirely removed.

Passing along the duct on the inside of such a screen a very pronounced sooty odour is noticeable, which cannot but be detrimental to the air continually passing through it. These screens are now frequently put up in small bays so as to be the more readily cleansed; but even under these circumstances, they are not satisfactory, for, to keep them in a condition approaching cleanliness, a large amount of water would be required continually (not intermittently) running down their surfaces when in use. This would be expensive, as the water after passing from the screen runs to waste.

This class of screen must be characterised as being somewhat dirty and capable of improvement, and a screen only flushed with water every ten minutes or so cannot be in such a condition to impart humidity to the air, as in the case where the surfaces are kept constantly wetted; for immediately after the flushing has ceased, the fibre commences to dry very rapidly, by the action of the large volume of air continually being pulled through it, so that in a few minutes the surfaces fail to impart that degree of humidity which was effected while the screen was thoroughly wetted, and immediately before the screen is reflushed (usually every ten or twelve minutes) little or no humidity is given to the air. The consequence of this is, that at one time the maximum degree of humidity is being given to the air, whilst just previously to the reflush, the filtering material passes practically dry air. The atmosphere in the rooms must, therefore, be affected by this variation, while, in a properly designed system, the degree of humidity is always constant.

(*d*) *The Revolving Fibre Screen.*—The material forming this screen is similar to that used in the last, but stoutly plaited. It passes over rollers at top and bottom, so that the air has to pass through a double thickness of material in its passage to the building. The screen is fitted with a low gear from the engine and revolves about twice every minute. At the bottom of the screen, a trough is supplied, and filled with water to the depth of about four inches. The screen, as it revolves, passes through the water, the trough being kept full and clean by a bib-cock continually and slowly running.

This is a much better kind of screen than the fixed fibre screen, and being of double thickness the air is twice screened, thereby a greater percentage of impurities is arrested than by the fixed fibre screen. Moreover, by dipping into the water at each revolution, the screen is always wet, and the continual revolutions wash it, and so prevent the soots and dust adhering to the material to the same extent as in the fixed fibre screen. The screen, being about 8 feet by 7 feet has therefore much less surface to be cleansed than a fixed fibre screen, as this latter, for a similar installation, has an area of about three hundred square feet.

There are these disadvantages, however; being of double thickness it puts more work on the engine; and by continually revolving, the screen tears, and requires to be occasionally repaired or renewed, and, like the fixed fibre screen, is not free from sooty odour.

(*e*) *The Cylindrical Revolving Screen.*—This screen consists of a drum (or a series of drums, as required), which are constructed of light steel framing, about seven feet long and seven feet diameter, covered all round and at one end with plaited fibre; the other end being open and connected with the duct. Beneath the drum is a brick trough containing water about fifteen inches deep, which is constantly being changed. The lower end of the drum dips into this, and, in revolving, keeps the whole surface of the fibre thoroughly wetted. The suspended particles are arrested by the material as the air passes through the fibre on its way to the propellers, and are immediately washed off by the drum revolving about five times a minute through the water in the trough. In this method, there is ample humidity given to the air, very little of the impurities pass the material, and the screen keeps much sweeter than either of the two previously described fibre screens; but there still remains a slightly sooty odour upon the material, although not nearly to the same extent. If fibre screens have to be adopted, this principle is undoubtedly by far the best of its kind, and the most cleanly of all the fibre screens.

It has been suggested by the advocates of the fixed fibre screens that revolving screens put unnecessary work on the engine, but the power required to revolve a screen at the rate of five revolutions, is so little that it may be entirely disregarded.

(*f*) *The Mist Screen.*—It cannot be said that a screen whose surfaces offer repose for soots, dust and other impurities, can be considered perfect or even satisfactory. With time and various experiments, this seemingly difficult problem has been solved in a most simple manner, which will be understood from the description and drawing, and which commends itself favourably on account of being cleanly, effective, hygienic, and inexpensive.

The method consists of fixing a sprinkler, within about two feet of the top of the brick-built intake shaft. The sprinkler is of copper. The four arms are fixed, and immediately under them is a propeller. By the action of the water discharging from the ends of the four arms, the propeller revolves very rapidly, and in its revolutions the water is thrown off the propeller in the form of very fine mist. This spreads over the entire area of the intake shaft, so that the air, in being drawn into the building, passes through this continuous screen of mist. At about three feet below the sprinkler, are galvanised corrugated iron sheets (similar to those adopted by the Sturtevant Company at Pitman's School of Shorthand, Southampton Row, W.C., but fixed differently), spaced about 1½ inches apart, and fixed vertically. The fine mist falls upon and between these galvanised

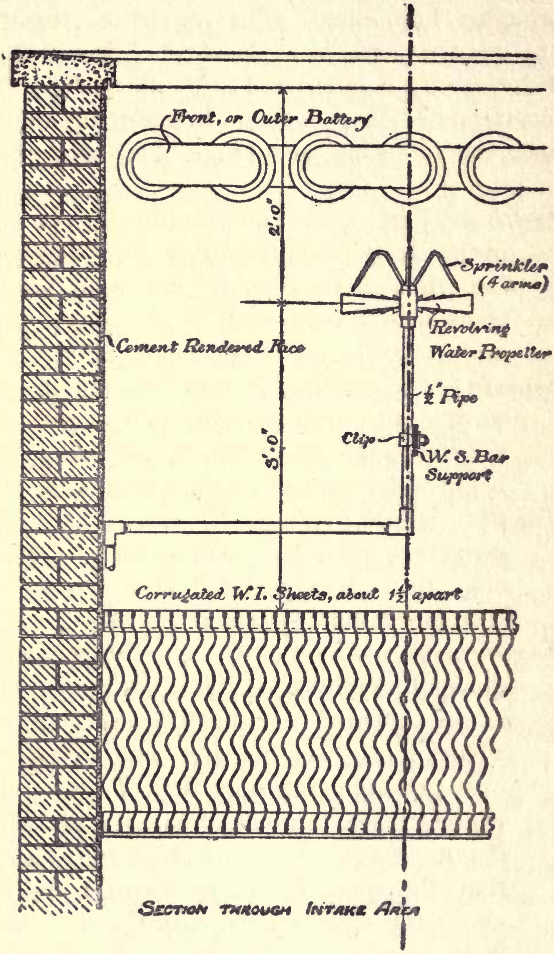

Fig. 1.

iron sheets, so that the air is again oscillated between the corrugations in its passage to the building. Every particle of air must necessarily come many times in contact with the wetted surfaces of these sheets, and by this means all suspended impurities are effectually removed, and at the same time, the air is thoroughly humidified. The impurities, together with the fine spray, fall from the sheets into a shallow bath below, which is connected to the drain.

This method of cleansing and humidifying the air possesses the following advantages over any other known purifier:—

*Firstly.*—There is no air continually passing over a dusty or sooty surface, for the galvanised iron sheets offer no lodgment for the soots, and consequently always keep clean and free from any odour whatever.*

*Secondly.*—Only sufficient water is required to revolve the propeller, the end of the four arms through which the water discharges being so fine as to be almost imperceptible.

*Thirdly.*—It offers much less resistance to the propellers than by passing air through a coke or a thickly plated fibre screen, and therefore requires less engine power.

*Fourthly.*—It surpasses all other systems in giving humidity to the incoming air, which is so essential for health, especially as whatever method be afterwards applied to raise the temperature of the air during the winter months, a good deal of the humidity, if not almost all, is sure to disappear; so that the more humidity is given to the air in the cleansing process, the less likely it is, after being heated, to be delivered into the rooms dry and parched. And during the summer months, when the batteries are not in use, it is being dried naturally, and the humidity evaporated by the atmosphere, as soon as the air passes into the room; so that the days upon which an excess of humidity may be thought to be apparent in the air would be but few during the year.

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* In a case where this method was firstly adopted by me, now seven years since, the surfaces of the sheets to-day are as clean as when they left the galvanisers.

# CHAPTER VII

## *DUCTS AND FLUES*

AFTER the air from the intake has passed the purifiers and humidifiers, it enters what is known as the main duct. This duct has branches called subsidiary ducts or feeders, and these connect to the vertical flues supplying the rooms.

All ducts should be formed of brick, with floors laid to falls to gulleys, and rendered throughout in Portland cement, finished with a fine metal-trowelled face. Stand pipes should be provided for hose, so that the ducts can be periodically washed down and kept quite clean, and free from dust.

Both the ducts and the subsidiary ducts have to be proportioned in size to suit the amount of air required for the building, but it is found in practice that the ducts require to be much larger than the total area of the flues which they feed. By this means they form a storage space for the air, and so enable a more even flow of air to pass into the rooms than would be the case, were the ducts only slightly larger than the area of the propellers supplying them.*

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* In some of the Installations in the North and Midlands (and particularly that provided at the Belfast Hospital) the ducts are several times the area of the propellers. This has proved greatly conducive to the regular flow of air, and it is to be recommended in every scheme where efficiency and not the initial cost is the first consideration.

In some systems the ducts are divided horizontally, into an upper and a lower duct. By this means the upper duct serves to convey heated air only and the lower duct cold air always. Where these two ducts connect with the flues, a vertical adjustable flap is provided for regulating the heated and the cold air, as will be described later.

There appears to be no real necessity for dividing the ducts, because air which is heated always rises, and by placing the heating batteries immediately against the mouth of the vertical flues and at the top of the duct, it necessarily follows that the heated air will be at the ceiling level. Consequently, if cold air be required in any particular room, the adjustable flap at the mouth of the flue is pushed up to the top of the opening, thereby shutting off all the heated air, and opening the space below the batteries for the cold air to ascend.

A double duct appears to be a waste of material. It is more trouble to keep clean and divides the height into two, which makes it too low and inconvenient for inspection purposes, it being very necessary that every main and subsidiary duct should be of sufficient height to enable the attendant to walk through it in an upright position when cleaning, and also when adjusting and readjusting the heated and cool air at the mouths of the vertical flues.

All flues should be built vertical if possible, and where this is not practicable, the bends should be curved very gradually. Directly a flue deviates from the vertical, friction increases, and the supply of air diminishes, so that, if two rooms of equal size have to be supplied with the same change of air per hour, the flue which is curved will have to be proportionately larger than the vertical flue.

The bottom of each flue should be supplied with a vertical sliding shutter, so made as to allow of its being fixed in any position necessary to control the warm or cold air to be delivered, as the case may be. This shutter does not affect the volume of air passing, but by raising it to the top of the flue, it cuts off the heated air coming from the battery, and allows only the cold air to pass through the flue, or by letting it down to the floor line, the maximum amount of heated air would pass through. By this means air can be delivered at almost any temperature required by the occupants of the individual room to which the flue connects.

Above this shutter a horizontal deal damper is supplied, which when pushed right back would prevent any air passing through the flue, thereby regulating the quantity of air to any number of changes per hour which might be desired.

A sliding door should also be provided at the entrance of each subsidiary duct, where it connects with the main duct. This controls the air to all the rooms fed by the subsidiary duct, and enables the whole of the air to be shut off, without interfering with each individual damper, and so constantly altering the flow of the air to the several rooms, as when the dampers are once properly adjusted, they should not be interfered with.

The shape and position of the mouth of the flue delivering the air into the rooms, is a matter which requires careful attention, in order to obtain perfect diffusion. It is of little use to blow the air into the rooms unless the position of the inlets and outlets are firstly decided upon by acquired knowledge, as on the disposition of the inlets and the outlets depends, in a large measure, the failure or success of the installation. The object should be to deliver the air in such a manner as, in its displacement, not to cause draughts; yet it must be delivered with sufficient velocity to create perfect circulation throughout the room operated upon.

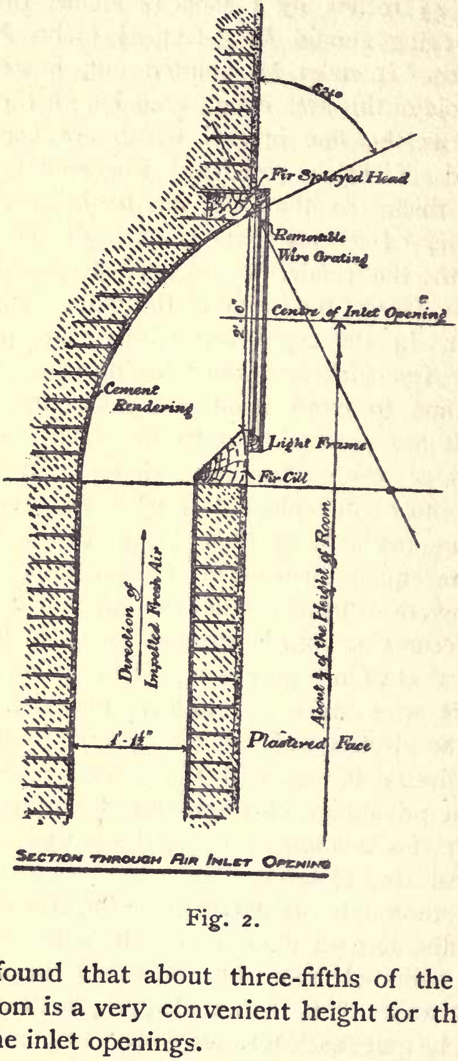


Fig. 2.

It is found that about three-fifths of the height of the room is a very convenient height for the mean line of the inlet openings.

The dimensions of the apertures will have to be proportioned to the sizes of the flues. The openings, however, should be quite a third larger than the area of the flues, so that, assuming a flue to be 3 feet 4½ inches by 1 foot 1½ inches, the area of the opening should be 3 feet 4½ inches by 1 foot 6 inches. It must be pointed out, however, that the whole of this area is not available for the delivery of air, as the flue breasts, which are usually constructed of brick (rendered in cement) are 4½ inches thick, so that the air, in being forced up the flue, as it nears the mouth of the opening, is, with the rendering and plastering, 6 inches from the face of the inside of the room; consequently the air, in its rapid vertical passage, passes the bottom few inches of the opening, and does not have time to exert itself in a horizontal direction until it has reached four to five inches above the bottom of the grating (see sketch). It has been found most convenient to curve the top of the opening (as shown)—this being the best means of more equally distributing the incoming air. The openings are usually filled in with iron or brass wire, secured to narrow grounds so as to be detachable for cleaning purposes. There is no necessity for this wire cover, as whatever material is placed over the opening reduces the area, consequently the air delivered is less, and the friction more. But it has the advantage of improving the appearance of a room, for a large open gap in a wall can hardly be considered pleasing.

For thorough circulation it is imperative that the inlet and extract flues be on the same wall of the room operated upon, but at nearly opposite ends of the wall. This is not always practicable, but it would be quite useless to provide an extract in the wall at the floor level immediately opposite the inlet: the air in such a case, would merely pass from the inlet directly to the outlet, without circulating throughout the room.

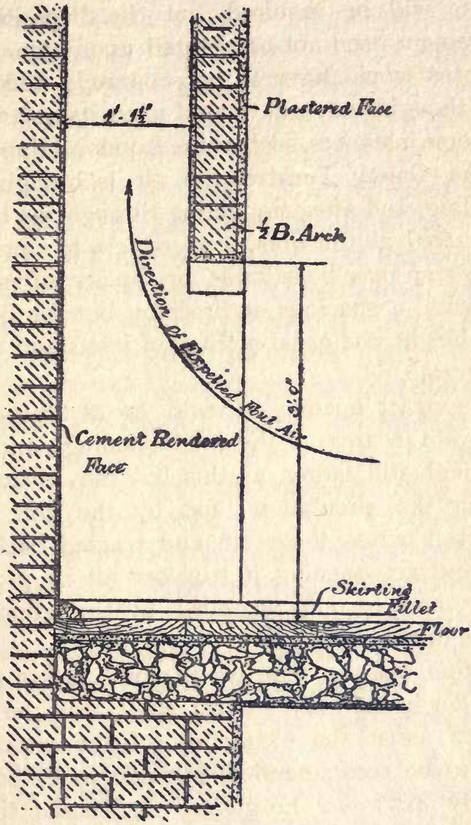
Where rooms are of large size, several inlets and extracts will be required, but the disposition and arrangement need not be entered upon here, as every such case would have to be separately and scientifically thought out, and treated upon its own merits.

In some instances, such as the London Hippodrome, and the Gaiety Theatre, the air is brought in at the ceiling, and after circulating through the building, is extracted at the floor level by electric propellers. This system may be suitable for a place of entertainment with a spacious auditorium, but for buildings of less height, the usual method of inlets and extracts is preferable.

The extract openings should be at least half as large again in area as the inlet openings, and where convenient, still larger, as this has the advantage of assisting the circulation ; for, by the time the air has passed across the room and reacted back again to the extract opening, it has lost all its propulsive velocity, and is only expelled by the atmospheric pressure in the room.

For this reason, some propulsion experts provide a propeller in the main extract shaft near the outlet, so as to assist the extraction of the vitiated air. This is to be recommended, but care must be taken that only *assistance* be given ; for, should the propeller be too powerful, it may draw the air directly from the inlet grating, thereby short-circuiting it, and preventing any circulation whatever in the room.

However carefully the windows and doors may be fitted, there is almost certain to be some escape of air—that is, the same amount of air will not be released by the extracts as is delivered. But making a slight allowance for this escape, experience has shown that the extracts act more efficiently when they are larger than the inlet gratings, so as to induce, or invite, the vitiated air to pass through the extract opening.



SECTION THROUGH AIR EXPULSION OPENING

Fig. 3.

The opening in the extract flue should be at the floor line, and if gas is to be used in the building, another opening, two-thirds of the area of the inlet opening, should be provided in the same flue, at the ceiling level. The top opening should be fitted with a light deal flap, and supplied with gearing to open horizontally. The bottom opening may either have a hinged flap, a light frame filled in with wirework, or simply left as an opening. This last is the most simple and the most preferable (see fig. 3), as the bottom extract should always be free to pass the vitiated air, while the top extract is only required to be opened when the gas is burning, for the purpose of carrying off the fumes of gas without bringing them down past the occupants of the room, in their passage to the floor extract. The provision of electric light does away with the necessity of a ceiling extract, and much simplifies the difficulties of maintaining an even temperature throughout the building.

It is very important that no obstacle be placed immediately in front of the extract gratings, as the circulation in that event would be checked.*

Where practicable, the whole of the extracts should be collected together in one main trunk, and the trunk carried to the highest part of the building, where the air is free to escape through out gratings.

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* It is not altogether uncommon to find a board has been placed against the extract opening, on account of an imaginary draught. That no serious draught exists, may be concluded from the fact that, at a few feet from an extract flue, not only is there insufficient air to register a record, but it will not revolve the anemometer, so feeble are the currents at this point.

## CHAPTER VIII

### *HEATING BATTERIES*

To warm the air, before it is delivered into the rooms, it has to be passed through fire or steam heaters, of sufficient capacity to raise the temperature to the required degree. These pipes when put together in the requisite number of sections are designated "Heating Batteries."

The batteries are sometimes placed immediately behind the air purifiers, in the single duct system, and immediately against the bottom of the vertical flues, in the double duct system; and, in some instances, in both positions.

Where the batteries are placed immediately behind the air purifiers, it necessarily follows that the whole of the air will be delivered into the rooms at nearly the same temperature, so that, if one person wishes the temperature of his or her room raised or lowered, this cannot be effected without raising or lowering the temperature of the remaining rooms to a corresponding degree. This, of course, is extremely inconvenient and undesirable. It might be, in fact often is, that one particular room may have been occupied for some hours (as in the case of a school classroom), while an adjoining room has remained unoccupied. If the occupants of the first room require the temperature lowered (as in practice any occupied room has a higher temperature, under similar conditions, than a room unoccupied), the room unoccupied must be correspondingly lowered in temperature, which would, in all probability, at the time be several degrees lower than the occupied room.

There is also this disadvantage; directly air leaves the heating medium, it commences to cool, and when the heating batteries are placed immediately against the air purifiers, it has to travel to the propellers through same, and along the main and subsidiary ducts, before it ascends the vertical flues. By the time it reaches this point, it will be several degrees lower than it was upon leaving the batteries; consequently the air requires raising to a greater temperature to allow for this cooling.

There is a further disadvantage. Suppose a room has been occupied and gas burning for some hours. It is found very refreshing to be able to give the room a good flush with cold air during the temporary absence of the occupants; but with the batteries in this position it cannot be done.

The most effectual, the most economical, and the system showing the greatest advantages, is that which has the heating batteries fixed immediately against the bottom of the vertical flues. By this means no heat is lost, the circulation is accelerated, and the maximum heat can be obtained; while practically the same temperature can be maintained in a room remote from the battery, as in those rooms in close proximity. Also, by the use of the sliding vertical shutter, the heat can be entirely shut off, or regulated to suit the convenience of any occupant of a particular room, and by the provision of a valve in the flow pipe, the whole battery can be shut off when the rooms in this section of the building are not required to be heated.

Each individual room in a building operated upon by this system should be under separate control, and no propulsion scheme can claim any degree of perfection, that cannot effect this purpose; for it must be remembered that the temperature and change of air which will suffice most admirably for one person, will be altogether wrong for another. Even the idiosyncrasies of faddists must have attention.

In some of the earlier propulsion installations, the air was warmed by means of coke-heated batteries. It is very easy, by carelessly overheating the tubes, to burn the air; and this is therefore a system not to be advocated where the air has to be breathed by human beings. The system is no doubt well adapted for drying rooms, etc., as it is the most economical method known, the cost of raising the temperature of a quantity of air being considerably less than where steam is used.

The universal system now adopted is to heat the air by means of steam, and whether this be done by means of pipes, coils, or batteries, it matters little; but from observations, the three-inch cast iron "gilled" pipes afford much more heating surface than the one-inch wrought iron pipes, and are therefore more economical; besides which, larger pipes are less likely to rust through and give trouble than smaller ones.

By steam heating, it is almost impossible to overheat the air, or rob it of much of its essential properties, as may be done when passing it through fire heated tubes.*

Of course, in any case, air has a tendency to dry when heated, but it must be remembered that the air is somewhat prepared for this drying, by being passed through the humidifiers.*

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* Having made some tests in this respect, showing the maximum temperature to which the air is raised by passing it through steam batteries, with a steam pressure of 20 lb. per

The temperatures to which the air should be raised depend upon the purposes for which the building is to be used; but speaking generally, a propulsion system can very easily—even in winter time—deliver air into the rooms which will maintain a temperature of 62° Fahr., while the external air registers 10° below freezing. Moreover, this temperature can be maintained throughout the day, within a variation of but one for two degrees, providing that the installation is complete and efficient in every respect, and has been properly calculated to perform its work.

An outer battery is sometimes provided, so that during frosty weather, the air is slightly heated before it reaches the filtration and humidifying screens.

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square inch, and the thermometer hung for fifteen minutes one inch away from the metal, the following were the results:—

| Outside temperature | Temperature of air one inch from batteries, with 15 minutes' test. | Number of degrees air was raised. |
|---|---|---|
| 39° | 87° | 48° |
| 35° | 94° | 59° |
| 42° | 93° | 51° |

It will be observed that in the three instances the maximum temperature to which the air is raised is 94°.

* To say that the air becomes dry when heated, is a convenient and general way of expressing that change which everybody recognises as taking place in the condition of the atmosphere consequent upon the rise in temperature. Such a statement is, theroetically, incorrect. The air, itself, does not necessarily become dry under these conditions; but its normally absorbent quality is greatly enhanced, so that the air coming into contact with the throat and lungs, abstracts their natural moisture, and gives rise to that irritating sense of aridity which is most readily expressed by saying "the air is dry." The only way to counteract this effect is by superhumidifying the air to an extent equal to its increased powers of absorption.

This prevents the water freezing upon the material and choking it. But there are only a few days in the year in this country when it would be required, consequently an outer battery has only been supplied in a few installations.

# CHAPTER IX

## *CHANGES OF AIR AND VELOCITIES OF DELIVERY*

A FEW years ago, in the earlier days of propulsion installations, it was considered a great achievement to be able to change the air in a room five times every hour, and it was also thought that this change was sufficient to keep a room sweet and free from odour, no matter how many occupants it accommodated. In the present day, speaking broadly, this change is proved to be quite inadequate, indeed experience leads one to the conclusion that, within reason, you can hardly supply too much air in a room, provided the air be properly heated and efficiently delivered. Where one complaint is made by the occupants, of an excess of air, twenty are made against an insufficiency.

As more attention has been given to this system of ventilation, so the necessity for a greater volume of air per person per hour has been apparent. The increase has been slow, but in modern installations, it is not an uncommon practice to have the whole of the air changed at least ten or twelve times per hour, that is, a complete change of air every five or six minutes.

After the installation has been at work for about half-an-hour, except on occasions where it is decided to suddenly change the temperature, the air delivered is practically at the same degree as that already occupying the room; draughts, therefore, can occur only when such changes are made. And since it is possible to effect the changes *gradually* if desired, the current of foreign temperature need scarcely be perceptible.

It necessarily follows that a propulsion system of ventilation is a very convenient method of keeping a building warm, sweet and healthy, and practically free from draughts.

No one can pretend to lay down a hard and fast line for the volume of air necessary to keep a room free from odour; everything depends upon circumstances. Every building, and every room in that building, must be specially considered and treated upon its merits or demerits. A scientist will inform us that two thousand cubic feet of air per person, per hour, should be supplied, another will state that the air in each room should be changed ten times per hour; but to accept these figures without applying them to the particular purpose for which the rooms are intended to be used, seems unwise.

Let us take, for instance, a ward in a hospital, and assume it to be 60 feet long, 20 feet broad, and 16 feet high, this would contain a cubical extent of 19,200 feet. Supposing the ward accommodated about 20 beds, allowing 2,000 cubic feet for each bed, would give a total of 40,000 cubic feet per hour of air required, which would mean that the air would be changed but twice every hour. In winter time, so slow a change would hardly be sufficient to keep the frost out of the ward. From this instance it will be realised that, under such circumstances, 2,000 cubic feet of air per person per hour would be totally inadequate.

Now, if we consider a classroom of a school under the same conditions, the results will be eminently satisfactory. Assume a classroom 25 feet by 24 feet and 14 feet high, the cubical extent would be about 8,400 feet, and such a room would accommodate 60 scholars; and 60 scholars, at 2,000 feet per scholar, would equal 120,000 cubic feet of air required per hour. If we divide this quantity of air by the cubical extent, it will give a change of air equal to 14·3 times per hour, which is about what is required for an average school classroom for a summer change, and this change of air can be effected without draughts, or discomforts in any way. It must be borne in mind that for schools—especially those schools in the poorer parts of London, and other large towns—a high change of air per hour is necessary, as the scholars who attend, do not reside in the West End, neither does their clothing consist of the finest, nor of the cleanliest material. Even with schools, there are cases where, in some districts, the classrooms are much sweeter and more free from odour with a change of air equal to seven times per hour, than the classroom at a school in a poorer district, having a change of air equal to fourteen times per hour. Where one or two occupy a room, it matters little; but where sixty of such children assemble together, especially upon a damp or wet day, the circumstances are quite different.

It, therefore, follows that no definite change, or volume of air per hour, can be accurately stated as applicable to all cases, common sense and judgment must be applied; nevertheless, where rooms are occupied by human beings, it may be stated as a general rule, that each person should have a minimum of two thousand cubic feet of air per hour in summer, providing the rooms are fully occupied; but in the case of a room only partially occupied, or a hospital, workhouse, and such like structures, where there is a considerable cubic space allowed for each person, the volume of air should never fall below a change equal to ten times per hour in summer or seven times in winter.

During the winter months, it is not usual to give quite so rapid a change of air per hour as in summer, although, chemically speaking, the air is not so pure as during the latter period—it rather points to the fact that a greater change of air should be supplied to make up for this loss of purity; but practically there is this difficulty; during hot, sultry summer days it is pleasant to have a volume of air circulating, but complaints would soon be rife, were the same volume of air, although heated, continually passing around one during the winter months.

In laying down an installation, it is always desirable to make provision for the maximum amount of air and heating surface required, plus a small percentage for loss and waste. It is so easy to arrange for this when going into the calculations, and at the time, does not perceptibly increase the cost; but when once the system is in working order, it is a most difficult matter to have to slightly enlarge a flue, which is found to be too small, or where the power of a battery has shown itself incapable of raising the temperature of the air to the required degree.

It is absolutely necessary that the whole of the subsidiary rooms in a building (where they communicate with the main rooms by means of doors which may be constantly opened and closed) should be operated upon by the system; otherwise, as soon as a door is opened which communicates with a room not operated upon, there is a rush of air from the surcharged room, which completely upsets the circulation in that room, and short-circuits the air from the inlet grating.

With regard to the velocities at which the air may be delivered into the rooms,—these, where the building is used for business or manufacture, may be varied to suit the particular purpose for which the installation is provided. But where the rooms are to be occupied by human beings, there must be a limit to the velocity of the air delivered, otherwise there might be a gale in a room, which would seriously inconvenience the occupants.

If we consider what should be a miximum summer velocity for a habitable building, then all other structures requiring a less change of air, need not exceed this velocity ; but in order to arrive at this maximum, we must firstly determine what class of building requires the greatest change of air.

Probably no building requires a greater change of air than a Public Elementary School situated in a poor district. Even a crowded political or social meeting must give way to these conditions.

It has been found in practice, and will be readily admitted by experts, that air during the summer months can be delivered into a room without causing draughts or inconvenience at any velocity not exceeding 6 feet per second,—that is, 360 feet per minute, or 21,600 feet per hour. It is not advisable to increase this velocity, except under exceptional circumstances, neither is it advantageous to allow the velocity to fall below 4 feet per second, during the winter months. The complete circulation of air will not be nearly so thorough as when the higher velocity is maintained. With a six feet velocity, it is sufficient to keep the air in a room on the move, even in the corners, so that no stagnation of air occurs anywhere ; whereas, if air enter a room much below four feet per second, it becomes sluggish, and the thorough circulation is retarded.

It may be said, and with some degree of reason, that such a large volume of air will require a large flue and a large opening, which must necessarily detract from the appearance of a room; but if covered with thin brass wire with a moulding around, they may be classed as presentable to the eye.

The necessary area of the inlet opening is, of course, a matter for calculation. As for example:

It is required to supply a classroom containing 60 scholars with 2,000 cubic feet of air per child, per hour—the rate of delivery being (say) 6 feet per second:—

Air required per child = 2,000 feet per hour.
„ for 60 = 2,000 feet × 60 = 120,000 feet pr. hr.
= 33⅓ feet per second.
Rate of delivery = 6 „ „
Opening required to admit
33⅓ feet per sec. = $\frac{33\frac{1}{3}}{6}$ square feet = 5½ square feet (approx.).

Assuming the flue to be (say) 3 ft. 4½ in. long, and the width of the opening to correspond, then to obtain an area of 5½ feet, the length of opening $= \frac{5 \text{ ft. } 6 \text{ in.}}{3 \text{ ft. } 4\frac{1}{2} \text{ in.}} = 1 \text{ ft. } 7\frac{1}{2} \text{ in.}$ (approximately). But, as previously stated, the bottom four or five inches of the opening is not really effective, where the flues are constructed in brickwork, so that, allowing for this, the aperture should be 3 ft. 4½ in. long by (say) 2 ft. high in the clear.

The air should ascend the vertical flues at, as nearly as possibly, the same velocities as that at which the air is delivered into the rooms. This is not always quite practicable, for, where the flues are executed in brickwork, brick dimensions should be adhered to, and the calculations will not always exactly work out. Taking the previous instance, with a flue 3 ft. 4½ in. long, required to deliver 5½ feet of air per second, this will equal 5 ft. 6 in. ÷ 3 ft. 4½ in. = 1 ft. 7½ in.; but, as this width is not a brick dimension, the flue, in practice, would be executed 3 ft. 4½ in. by 1 ft. 6 in. in width; this would increase the velocity of air in the flue (after deducting ½-in. rendering) to 7½ feet per second. There is no real objection to this; but, as previously stated, it is as well to maintain the same velocity (as nearly as possible) in the flues as at the point of delivery, where this can conveniently be done.

A velocity of three hundred and sixty feet per minute may appear to be abnormally high. In reality it is not so—it is a good one, but with modern propulsion installations it is a very general one. Many rooms are being supplied with air at a much higher velocity.*

It must be remembered that as soon as the air leaves the inlet grating, the velocity is reduced, owing to the air being released from the flue and immediately commencing to spread and diffuse in the room; so that, if air be delivered at a velocity of 6 feet per second, at the moment of leaving the grating through which it is discharged, by the time it has passed 2 feet from the grating, the velocity would be reduced to about 3½ feet per second, and at 4 feet distance from the grating, the velocity would be but 2 feet per second, and after this the movement becomes very slight. Therefore, although the air is forced into the room at the rate of 6 feet per second, by the time it reaches the occupants, nearly the whole of its velocity is lost, by the air being dispersed and distributed.

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* A building in London might be instanced, consisting of about 30 rooms, where 3 of the rooms are supplied with air at a velocity exceeding 600 feet per minute—equal to 10 feet per second (effecting a change of air 14 times per hour), and yet the occupants of these rooms prefer them to any of the remaining rooms in the same building, which have a less velocity and change of air.

# CHAPTER X

## *DUST*

THE question of dust is a subject which, at first sight, may appear to be relatively unimportant, but which, nevertheless, very largely influences the success or ultimate failure of the installation. No matter what precautions be taken, dust will find its way into a building; in fact, it will penetrate almost anywhere, and as it cannot be absolutely excluded in practice, arrangements must be made within the building to remove it from the surfaces upon which it is deposited.

By merely opening the windows of a room in any large town, every one has observed the quantity of dust which will accumulate in a short space of time. Much more so is the case when such huge volumes of air are propelled into a building which is ventilated upon the Plenum system, for the filtering process is effective only to a limited extent. A great quantity of the suspended particles in the atmosphere are arrested as the air passes through the screens, but not all; it is the fine heavy particles which have a tendency to more freely pass the screens. These particles constitute what is known as "dust," and not the light impurities such as soots, as these latter are larger in bulk, and by being lighter, are more readily caught by the filtering material.

At the same time, it must not be inferred that the screens do not perform their work, for were they not provided to filter the air in a building operated upon the Plenum system in London, or any of the large towns in the Provinces, the dust and filth would be so objectionable as to become dangerous to health.

Then again, in the majority of installations, the apparatus is only in operation during the day ; and as soon as the propellers cease work, it is customary to close the doors at the foot of the air intake, and so prevent any air passing into the building during the night. But in practice, these doors do not exclude the whole of the air, they would have to fit with mathematical accuracy to do so, there is always a leakage, and this is accelerated by reason of the ducts and flues being warmed by the day's working and so sucking or drawing the air through the joints between the doors and the frames.

It is this which brings more dust into the ducts, than is the case when the apparatus is at work and the air screens in operation. The dust, however, rarely finds its way into the rooms of the building during the night, and there is insufficient current to raise it vertically through the flues; but what is worse, it forms deposits upon the heating batteries. Were it to fall upon the floor only, of the ducts, it could be easily removed in the usual way, by flushing with the hose; but to remove it from the surfaces of the batteries, coils, and pipes presents more difficulty. In the first place, the pipes comprising the batteries are usually "gilled" and being grouped closely together in sections, offer considerable difficulty to the attendant in endeavouring to cleanse the whole of the surfaces. Secondly, it would not do to play cold water upon a battery whilst hot, and by the time the batteries have cooled down after the day's work (unless rigid supervision is in force) it is very doubtful whether it would not be too late for the attendant to commence work again; and thirdly, are the batteries prepared to receive constant cleansing by means of water from a hose? *

This matter appears to be too generally overlooked by Plenum experts. The apparatus is installed, the necessary changes of air provided, every one is satisfied with the results at the opening of the building, and the Plenum engineer walks away saying: "That's all right." Never was there a greater fallacy. Wherever mechanical apparatus is in use, attention must be constant, however excellently the installation has been carried out. It is of little use dumping down the apparatus, and leaving it to take care of itself.

Every pipe, coil, and heating battery, in connection with the installation, should be galvanised before being put together. Although adding a little expense to the original outlay, it is amply justified by the result. Were the surfaces to be galvanised they would radiate slightly more heat than is given from the invariably rusty surfaces; they would offer less lodgment for the dust, and would be easily cleansed with the hose.

By far the most important point in connection with this matter, is the injury done to the incoming air by its having of necessity to pass over these dusty surfaces, especially when the heating batteries are in use. Directly the steam is turned on a most unpleasant odour arises from the dust becoming heated, and possibly myriads of bacteria are consequently

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* The writer has inspected fully fifty Plenum installations in all parts of England, but in no single instance have the heating batteries been coated with any preservative material, to enable them to be kept clean or to keep them from rusting away.

brought into life, and propelled with the air into the various rooms of the building.*

It is of the utmost importance that all surfaces exposed to the intake air should be kept absolutely free from rust or deposited dust.

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* A little while since, the writer was called in to investigate and report upon complaints which were being made by the occupants of a building in the East of London, ventilated upon the Plenum System. Upon visiting the building, it was found that several of the air inlet gratings were partially blocked up, so that only a proportion of the air arranged for, could pass into the rooms. Upon enquiring the reason of this curtailment of the air, one of the occupants stated the air delivered was bad air, it always "gave a headache" and "the less one had of it the better." This remark was repeated by several of the occupants, and appeared to be serious, as the change of air in the rooms was very slight where the inlet gratings were practically covered up (the rooms being fully occupied) and the whole of the windows were kept closed "by order." Upon visiting the basement, it was found that the temperature was raised by means of a main heating battery of considerable proportions, and consisting of a number of small "gilled" pipes, which had been in use about five years. No provision whatever had been made for cleaning the battery nor to protect it from rust, consequently the humidified air, passing over it continuously for five years, had shown its effect upon the surfaces of the metal. It was covered with rust and dust, and appeared never to have been cleansed since it was installed.

The propellers were temporarily switched off, and as soon as the rush of air had ceased passing the battery and it became reduced to a slight velocity, a very pronounced and objectionable odour was noticeable. It was, without doubt, the air passing over these rusty, dusty surfaces that was making it "bad air," as the occupants called it, and was affecting the health of those constantly occupying the building for a number of hours every day.

The writer is of opinion that what amongst anti-plenumists is called "Plenum Air" is attributable solely to this cause.

# CHAPTER XI

## *COST*

IN dealing with the question of the cost of a Plenum Installation, it is necessary to consider firstly, the original or initial outlay, and secondly, the maintenance or cost of running the apparatus, as compared with expenditure incurred in adopting any other method of heating and ventilation.

In the case of a propulsion system, the larger the installation the less will be the cost, *pro rata*, to the amount of air supplied. It hardly matters what building is taken as a type, for any structure would necessarily have to be provided with one or other system of heating, and what concerns us is to know what would be the additional cost of providing and maintaining a propulsion system, over that of hot water heating or open fireplaces—the two latter of course, without mechanical ventilation.

Assume a building (either a manufactory, workshop, or school) accommodating 1,200 workpeople or scholars, and allow for each person 2,000 cubic feet of air per hour, the total cubic feet of air per hour would be 2,400,000.

### INITIAL COST

To instal a propulsion system capable of supplying this quantity of air, and providing an isolated chamber for the mechanical apparatus, including the formation of ducts, flues, inlets, extracts, and all other sundry builders' work, would be the sum of about £2,500. To this sum must be added £1,500 for the provision of boilers, pumps, batteries, propellers, gas engine or electric motor, and other sundry mechanical apparatus, making a total initial outlay of about £4,000.

To provide a similar building with a hot water apparatus, the cost would be about £1,085 for the basement, furnace flue, channels and builders' work, in cutting away for, and making good to, and the sum of about £915 for the hot water apparatus, or a total initial outlay of about £2,000.

For a similar structure with open fireplaces, the cost of providing coal cellar, chimney breasts, flues, chimney stacks, with architectural finishings, and stoves and mantels, etc., would be about £1,800.

The propulsion system will therefore in the first instance cost about £2,000 more than a hot water apparatus, and about £2,200 more than open fireplaces.

## MAINTENANCE

*Propulsion Installation.*

Every time the fire is relighted, in order to get up steam during the winter months, it would take about 3 hours, and require about 3½ cwt., of coal at 24*s.* per ton, value 4*s.* 2*d.*; but as the fires are banked up every night, and only drawn usually at each week end, this item would only amount to (30 weeks from October to April inclusive) £6 5*s.* 0*d.* per annum.

The cost of maintenance per hour of occupation would be as follows :—

| | s. | d. |
|---|---|---|
| Coal, 1 cwt. at 24*s.* ... ... ... ... | 1 | 2 |
| Gas Engine, 200 feet of gas at 2*s.* 3*d.* ... per 1000 ... ... ... ... ... | | 5½ |
| Water for filtering and humidifying 50 gallons at 10*d.* per 1000 gall. ... ... ... | | ½ |
| Total per hour ... | 1 | 8 |

But if wages be included for mechanic, say 10*d.* per hour, the total cost would be 2*s.* 6*d.* per hour.

During the summer months, however, only the propellers and humidifiers would be in use, the cost of which would be 6*d.* per hour for gas and water.

Now, estimating that the heating will be required for thirty weeks from October to April in each year (both months inclusive), the minimum cost of working the apparatus per annum, for say, 10 hours per day and 4 hours on Saturdays, for 300 working days, would be as follows:—

| | £ | s. | d. |
|---|---|---|---|
| Initial cost of getting up steam, 30 occasions at 4*s.* 2*d.* ... ... ... ... ... | 6 | 5 | 0 |
| Coal, 54 cwt. per week for 28 weeks = 75 tons at 24*s.* ... ... ... ... | 90 | 0 | 0 |
| Gas engine, 54 hours per week, for say 43 weeks = 2,322 hours at 200 feet of gas per hour = 464,000 at 2*s.* 3*d.* ... ... | 52 | 4 | 0 |
| Water, 2,322 hours, at 50 gallons per hour = 116,000 gallons at 10*d.* ... ... | 4 | 17 | 0 |
| Oil, waste, repackings, repairs, and renewals | 20 | 0 | 0 |
| | £173 | 6 | 0 |
| * Add wages of skilled mechanic, 52 weeks at 45*s.* ... ... ... ... ... | 117 | 0 | 0 |
| Total cost of maintenance per annum | £290 | 6 | 0 |

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* The mechanic would not necessarily devote the whole of his time to the working of the apparatus—but this would apply

*Hot Water Apparatus.*

| | £ | s. | d. |
|---|---|---|---|
| Initial cost of heating water, 30 occasions at 4*s.* 2*d.* ... ... ... ... ... | 6 | 5 | 0 |
| Coal, ¾ cwt. per hour = 41 cwt. per week for 28 weeks = 58 tons at 24*s.* ... ... | 69 | 12 | 0 |
| Add for water, repacking, cleaning boiler periodically, renewals, etc. ... ... | 14 | 0 | 0 |
| | £89 | 17 | 0 |
| Add wages for unskilled attendant, 52 weeks at 35*s.* ... ... ... ... ... | 91 | 0 | 0 |
| Total cost of maintenance per annum | £180 | 17 | 0 |

*Open Fireplaces.*

| | £ | s. | d. |
|---|---|---|---|
| 36 fireplaces consuming ½ cwt. of coal for 5 days a week and ¼ cwt. on Saturdays = 2¾ cwt. per week for each fireplace = 91½ cwt. per week for 36 fireplaces, and for 28 weeks = 128 tons at £1 1*s.* 6*d.* ... | 137 | 12 | 0 |
| Cost of lighting 6,048 fires (wood, matches, etc.) at ¼*d.* ... ... ... ... ... | 6 | 6 | 0 |
| Repairs to 36 stoves at 10*s.* each per annum | 18 | 0 | 0 |
| Renewals of fire irons, etc., 36 fireplaces at 1*s.* 6*d.* ... ... ... ... ... | 2 | 14 | 0 |
| | £164 | 12 | 0 |
| Add wages for unskilled attendant, 52 weeks at 35*s.* ... ... ... ... ... | 91 | 0 | 0 |
| Total cost of maintenance per annum | £255 | 12 | 0 |

The comparative cost of the three systems, including six per cent. interes tp e rannum on the

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to the comparative cases also; as other odd jobs in connection with the building would be found to fill up any spare time the mechanic might have, whether the building were heated by Plenum system, hot water, or open fireplaces.

initial outlay in combination with the Total Maintenance per annum, would be as follows :—

| | Propulsion. | | Hot water. | | Open fireplaces. | |
|---|---|---|---|---|---|---|
| | £ | s. | £ | s. | £ | s. |
| Initial outlay, | 4000 | 0 | 2000 | 0 | 1800 | 0 |
| 6% on total initial outlay, | 240 | 0 | 120 | 0 | 108 | 0 |
| Maintenance per annum, | 290 | 6 | 180 | 17 | 255 | 12 |
| Totals per annum, allowing 6% interest on initial outlay and maintenance charges, | 530 | 6 | 300 | 17 | 363 | 12 |

It will thus be observed that the luxury of a propulsion installation for a building containing about a quarter of a million cubic feet, will entail a total annual cost of about £229 per annum in excess of a hot water apparatus, and about £166 per annum in excess of open fires ; but it must not be forgotten that for this additional annual outlay, something like 5,572,800,000 cubic feet, or about 186,589 tons of filtered, humidified and warmed air would be thrown in as a *quid pro quo.*

# CHAPTER XII

## *SPECIFICATION*

IN the infancy of all the branches allied to building, it has been customary for the designer or expert, besides preparing his schemes, to be responsible for and to carry out the work himself. It was so in the history of Electricity, Sanitation, Steam, and Hot Water Installation, and to go back further, even Architecture itself. The architect, and the various consulting engineers are products of a more mature development of the several industries to which they are respectively attached.

Plenum Ventilation may be said to be in its infancy still, and whatever may lie in its future, at the present time, the expert is generally the contractor for his particular branch of the work.

The architect, in his dealings with the building contractors, is himself the expert, and rightly assumes supreme command, but in his relationship with the propulsion engineer, he has to treat at the same time with the contractor and the expert. The exact position of the architect with regard to this part of the work, may appear at first to be somewhat undefined; but with a little thought, his exact province may be easily decided.

With what information he has had placed before him in these pages, it is hoped that he will be able to adopt the attitude of an architect towards a contractor in this respect, to instruct the engineer as to what is required, and to see that his instructions are carried out; and in this way to do justice to his clients and to himself.

At the same time, it must be remembered that the engineer is an expert, while as regards the more elaborate calculations the architect is but a layman in comparison, and therefore must not hamper him in such matters, especially in determining the position of the more mechanical parts, and the areas and dispositions of the air inlets and extracts, should also be left entirely in the hands of the engineer. These two latter in no case need interfere with the architectural treatment of the building; but their sizes and relationship to one another are of such vital importance to the success or failure of the installation, that a free hand should be allowed the engineer who has perhaps made a special study, and has acquired a long experience in the determination of their relative positions.

In short, the architect should be in a position to guide, and *only to guide*, the engineer as to the essential requirements of the particular building to be operated upon, and since the contract should constitute a sufficient guarantee of complete and satisfactory carrying out of these requirements, it is only fair to leave the more detailed carrying out of these particulars in the unfettered hands of the engineer.

Such a course does not deter the architect from supplying a specification of the work to be done, from the point of view of the results to be attained, and also of such details as naturally come directly under his jurisdiction. A specification can be so written as to give the engineer the necessary amount of freedom to enable him to perfect a scheme, and at the same time, be so concise as to form a basis upon which he can estimate in a sound and business-like manner, thus eliminating so much of the speculative element, which, where no check has been possible upon the Plenum Engineer, has hitherto so often proved the source of failure of what otherwise might have been a very successful installation.

The following is a typical outline Specification to *govern* the calculations and arrangements of a Plenum Installation :—

### PRELIMINARY

The Engineer to prepare and submit plans and sections, with such detail drawings as may be necessary, showing the scheme he proposes to adopt, and with such written descriptions required to make same intelligible. Stating also, what the Engineer is to do, and precisely what is left for the General Contractor.

The whole of the work to be executed to the entire satisfaction of the Architect.

The Engineer to carry out his work with despatch, so as not to hinder or delay the Building Contractor, and he will be held responsible for any claim the Contractor may make for the non-fulfilment of this condition.

The Engineer to maintain and uphold in good working order, all apparatus supplied by, or fixed by him, for a period of twelve months after the work is handed over.

The Engineer to run the installation at his own expense for a period of one month from the date of occupation of the building, and during this period to instruct the mechanic who will take permanent charge of the installation.

The mechanical and working parts of the apparatus to be arranged in a separate chamber outside the walls of the main building.

The builders' and other tradesmen's work in connection with the heating and ventilation will be executed by the General Contractor in a manner to meet the requirements of the Engineer.

Payments will be made from time to time to the Engineer, equal to eighty per cent. of the value of the work actually fixed, and equal to ninety per cent. when the work is finished. Ten per cent. of the contract sum will be retained for a period of twelve months after the apparatus is completed, as a guarantee that the whole of the Architect's requirements have been complied with, and the installation working satisfactorily.

## AIR

The air intake to be at a height of at least ten feet from the ground level.

The Engineer to provide for changes of air to be made in the following rooms at the respective rates here stated, etc., etc., viz.:— *

The air to be delivered into the various rooms at a velocity not less than four feet and not exceeding five

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* The following table shows the suggested number of times per hour for changing the air in typical cases:—

HOSPITALS

| | Number of times air to be changed. | |
|---|---|---|
| | *Winter.* | *Summer.* |
| Outpatients' department ... ... | 9 | 12 |
| Wards ... ... ... ... ... | 7 | 10 |
| Day rooms ... ... ... ... | 6 | 9 |
| Operating Theatre ... ... ... | 5 | 8 |
| Lecture rooms ... ... ... ... | 5 | 8 |
| Administrative rooms ... ... ... | 5 | 8 |
| Corridors ... ... ... ... | 4 | 6 |
| Lavatories, W.C.'s, etc. ... ... | 4 | 6 |

feet per second in winter, and not less than five feet and not exceeding six feet per second in summer.

## BOILERS

Supply a Lancashire or a Cornish steel boiler of approved manufacture, tested to 200 lb. per square inch, and of size best suited for the work it has to perform.

The mountings and fittings to be of approved make, and stamped with the manufacturer's name.

The setting of the boiler will be executed by the building contractor from particulars furnished by the engineer.

## GAS ENGINE

Supply a gas engine of the "Otto," "Stockport," or "National" type, and of such brake power that, when working with London gas, it shall be capable of driving the full load to be covered for a period of at least three hours, and shall perform this work when one charge is cut off by the governor in

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| | | |
|---|---|---|
| **PUBLIC OFFICES** | | |
| Council Chamber ... ... ... | 7 | 10 |
| Offices ... ... ... ... ... | 7 | 10 |
| Committee rooms ... ... ... | 6 | 9 |
| Halls ... ... ... ... ... | 6 | 9 |
| Corridors ... ... ... ... | 4 | 6 |
| Lavatories, W.C.'s, etc. ... ... | 4 | 6 |
| **SCHOOLS** | | |
| Classrooms ... ... ... ... | 10 | 14 |
| Halls (Ground floor only) ... ... | 10 | 14 |
| Halls (above Ground floor) ... ... | 8 | 12 |
| Science and Art and upper standard rooms, etc. ... ... ... ... | 7 | 10 |
| Teachers' rooms ... ... ... | 5 | 8 |
| Corridors ... ... ... ... | 4 | 6 |
| Cloakrooms and Lavatories ... ... | 4 | 6 |

every four charges—that is to say, the engine shall be capable, when firing every possible time, of taking 25% overload.*

The engine to be set upon a concrete base overlaying a double thickness of creosoted railway sleepers.

Supply sufficient cooling tank accommodation in order to return the water to the cylinder at a temperature not exceeding 90° Fahr. after the engine has been running continually for twelve hours.

## MOTOR

The motor to be of the semi-enclosed type and to be of sufficient brake horse power to run continually at full load without showing any signs of "sparkling" at the brushes, and the temperature not to exceed 40° C. on windings, and 45° C. on commutations, after running twelve hours consecutively at full load.

Include for all necessary switches, motor starter, and speed regulator as required.

## AIR PURIFIERS AND HUMIDIFIERS

The air before being delivered into the building, is to be passed through a filtering and humidifying screen, the form, size, and material, to be left to the Engineer, but the screen must thoroughly cleanse and humidify the air with the minimum expenditure of water, and be capable of being periodically and entirely cleansed and freed from odour or deposit of any kind.

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* In order to insure more perfect balance and ease in running, each engine should be supplied with two fly wheels. Engines exceeding 12 brake power, should also be fitted with self-starters, because, above this brake power, the engines become too heavy for one man to conveniently start them by the ordinary method.

## PROPELLERS

The propellers to be of the straight-through volume type, with peripheral flange, and of such size that they will be capable of delivering the maximum volume of air required whilst not exceeding 280 revolutions per minute.

The bearings to be phospor bronze, self lubricating.

Two pulleys to be fixed to each propeller, of the respective diameters required to effect the prescribed winter and summer changes.

## DUCTS

The size and arrangement of the ducts to be left to the Engineer, but consideration should be given to making use of the walls of the main building in determining their disposition in order to minimise the cost of construction. The main duct should be spacious and in straight line from the propeller, for a distance of at least ten diameters of the propeller.

The subsidiary ducts in every case to be not less than seven feet in height.

The whole of the ducts to be laid to falls to gulleys, and all surfaces to be rendered in cement and trowelled wet with a metal trowel to a fine surface. The rendering at all internal angles to form a rounded hollow in the shape of a quadrant of a circle of six-inch radius.

All right angles in course of the main duct to be avoided—where not in straight line the ducts to be curved with an easy sweep.

Lay on water at convenient positions for effectually cleansing the ducts, etc.

Supply sliding doors to each subsidiary duct for shutting off sections not in use.

## FLUES

The flues to rise vertically from the subsidiary ducts to the various rooms operated upon, where bends are unavoidable the flues are to be proportionately increased in area to overcome the additional friction, brick dimensions to be adhered to, and all flues to be rendered in cement as specified for "ducts."

At base of each flue supply one-inch deal horizontal damper to regulate the quantity of air to be delivered, and allow for lettering on same necessary for identification.

Also at base of each flue supply one-inch deal vertical sliding and balanced shutter to regulate the temperature of the air delivered, lettered as before.

## AIR INLETS

The disposition of the air inlets to be left to the discretion of the Engineer, the backs of the flues to be gathered over towards the front with a curve sufficiently easy to form a tangent of 62½° where it meets the vertical face of the wall. The openings to be proportioned so as to deliver the summer change of air with a velocity not exceeding six feet per second, as ascertained with the anemometer immediately in front of the opening.

The height of each inlet from the floor level shall be three-fifths of the height of the room operated upon, measured from the centre of the inlet opening. Each inlet to have light brass wirework 2½-inch mesh in deal frame, fitted with dogcart latches to remove for cleaning purposes.

## EXTRACTS

The position of the extract openings to be left to the Engineer.

The openings to be at the floor level and to be half as large again in area as the inlet opening in the same room—no flap required for this extract.

At ceiling level, form an opening two-thirds the area of the air inlet opening, and connect same to the extract flue—the opening to be fitted with one-inch hinged deal flap, and supplied with gearing for opening and closing (so as to carry off fumes when gas is in use).

The extracts to be grouped together as much as possible in the same walls, and connected above ceilings of highest floor into trunks, and thence to vertical brick stacks, finished with solid tops, and open sides filled in with galvanised wire, to allow the vitiated air to freely escape, and in each case the extract shafts to be arranged so as to be remote from the air inlet shaft.

## HEATING BATTERIES

The heating to be effected by means of low pressure (not exceeding 20 lb. per square inch) steam.

The pipes to be high pressure solid drawn weldless steel steam tube of the recognised weights, with screwed ends and sockets, and connectors as necessary.

The heating batteries to be composed of cast iron gilled pipes 3 inches internal diameter, with 18 gills, 9 inches diameter of $\frac{1}{8}$-inch metal cast upon each 3 feet length of pipe, and arranged in sections as required, and fixed upon iron carriers immediately against the vertical flues, each section to be provided with a screw-down gun-metal regulating valve.

The batteries to be of sufficient heating surface to raise the temperature of the air delivered into the various rooms to 62° Fahr. at nine o'clock in the morning, when the external air is 22° Fahr.

*Note.*— Certain rooms require to have the air heated to a greater temperature.

The condensation water from the heating batteries to gravitate to a receiver and thence conveyed to the boiler by means of an automatic feed pump.

Supply outer or frost batteries to prevent the water freezing upon the surface of the purifying screens.

No flow or return pipes to be laid so as to impede the traversing of the ducts. Where necessary to cross the ducts near the floor, the pipes shall be laid in and finished flush with the surface of the floor.

## SUNDRIES

Supply telephones from a convenient position on each floor, communicating with the engine-room.

Supply iron step ladder from floor of boiler-room to top of boiler setting.

The whole of the interior and exterior of gilled pipes comprising the heating batteries, and steam pipes and other ironwork within the ducts, to be galvanised by an approved galvaniser.

The exposed surface of the boiler—except the front —also the main steam and return pipes outside the ducts are to be covered with non-conducting material.

Were some such general clauses as these imposed upon the engineer to guide and assist him in the preparation of his scheme, the writer feels convinced the result would be greater efficiency of the installation; and the architect, in so far as warming and ventilation is concerned, would feel that he was not only taking an intelligent interest in the scheme, but would also have the satisfaction of knowing that the requirements of the building were being carried out upon a more businesslike basis, than when the whole of the arrangements are left entirely in the hands or the Plenum engineer.

## CHAPTER XIII

### *TESTING*

PRESUMING the architect will specify the results to be attained by the engineer as regards the changes of air required, it will be necessary for the architect to be in a position to ascertain, on the completion of the work, whether the contract has been duly carried out in this respect.

For this purpose it is necessary to provide an "Anemometer" (or air-meter). This is an instrument fitted with a dial similar to that upon a gas or water meter, but about 2¼ inch diameter, which has a large hand indicating the feet from one to one hundred in the outer perimeter, and five inner dials indicating, hundreds, thousands, tens of thousands, hundreds of thousands, and millions. Above this dial, but connected with it, is a propeller-like fan, about 2¾ inches diameter, consisting of eight blades. This propeller in revolving indicates the velocity of the air in feet upon the dial below. The propeller will move either forwards or backwards, so that, if the instrument is placed with its back against an inlet, it will register forward, but with its back to an extract opening it will register backwards. A switch is provided, so that the propeller will revolve without registering upon the dial. This is necessary in testing, in order that the propeller may firstly get up speed, before the time is taken upon the watch for the test; otherwise, if the instrument were placed against the air inlet, and the time taken from the same moment, notwithstanding its being extremely sensitive and delicate, there would be a slight loss in the record as it would take a few revolutions in order to gradually attain the maximum speed at which the velocity of the air would revolve it.

There is another point to bear in mind ; with all mechanical contrivances, friction has to be considered, and in the case of anemometers, 30 feet should be added to the number registered, for every minute test to allow for this loss ; for, were there no friction, the instrument would register 30 additional feet every minute ; but there being friction, if the dial registers 280 revolutions per minute, 30 has to be added, making the reading for the subsequent calculations 310 feet per minute ; and where a five minutes' test is being made, 5 times 30, or 150 feet would have to be added to the index reading, in order to arrive at the correct velocity.

Before commencing the test, the architect should see that the rooms are in their usual and ordinary condition, in regard to doors, windows, etc., and that the apparatus has been at work for at least ten minutes prior to taking a reading. The necessity for this is that, before starting the apparatus, the air in the rooms is normal, but as soon as the propellers are switched on, the air immediately commences to be slightly surcharged or put under pressure. In the first minute or two, the incoming air has not time to exert itself and diffuse evenly throughout the room ; also the air will travel at a slightly greater velocity when the propellers are first started, because there is no pressure in the room, and consequently less resistance to retard its flow. But as soon as the room becomes surcharged, the velocity will become slightly reduced from that at starting, and when the apparatus has been running for, say, ten minutes, the velocity will remain constant, day and night, so long as the propellers maintain the same number of revolutions.

Some architects hold that the change of air within a room is equal to the amount of air which is calculated at the mouth of the extract flue, while others hold that the change is equal to the amount of air passing through the inlet opening. In every case, however well fitted the doors and windows may be, there is always a leakage, so that, as has been previously mentioned, the full volume of air delivered through the inlet opening cannot be registered in the extract opening. But it appears incorrect to assume that because a small quantity of air escapes, it has not played its part in its passage, by being inhaled and exhaled by the occupants of the room; and if such be the case it matters little whether a small percentage of the air escape through the joints of the windows or otherwise, or the whole of it be extracted at the opening arranged for the purpose.

The leakage varies considerably with the number of windows in a room, their relative positions, and particularly according as sashes are well or badly fitted.

Suppose for a moment no extract were to be provided for a particular room, and there were windows in three sides with very badly fitted sashes; let a given quantity of air be propelled into the room as ascertained by the anemometer, and assume the whole of this air could be expelled through the wide joints in the sashes; would it be maintained under such circumstances, that there is no ventilation in the room? Admittedly, it would not be properly distributed, and would be otherwise defective; but ventilation would still be going on, otherwise what would become of the air which it is known is being propelled into the room?

It is, therefore, incorrect and misleading to calculate the air passing through the extract opening as indicating the accurate change of air in the room, for the changes of air within a room will always be in excess of what the calculations show from the readings at the extract opening.

If a certain volume of air is being delivered into a room, and even though there be a small percentage of leakage, surely this actual, is also the true volume of air upon which the calculations should be based.

In nineteen Plenum Installations out of every twenty, the air is controlled and regulated at the inlet flue, and not at the extract flue; therefore, in practice, it is much more correct to take the tests at the opening which is directly under control, and which can be easily adjusted so as to afford the prescribed volume of air; for, where the tests are taken at the extract opening and the air adjusted at the inlet flue, it becomes quite a complication to accurately adjust the damper so that the proper volume of air is delivered.

Further, where gas is in use, there is an upper as well as a lower extract opening, leading into the same flue. In such case, it would be necessary to take the readings of each opening, if the volume of air is to be adjusted by the amount of air extracted. This would not only mean double work, but, since the upper extract could only be reached by means of steps or a ladder, it would be very inconvenient, complicated, and likely to lead to error.

In testing, the architect should not place himself directly in front of the inlet grating, as the incoming air, meeting part of the body, would have its flow slightly checked, and the reading would be incorrect. The anemometer should be screwed to the end of a long arm to enable the person testing to be entirely below the inlet grating, and so that only the instrument is exposed to the incoming air. Before commencing to test, it will be found convenient to calculate and tabulate the cubical extents of the whole of the rooms in the building operated upon by the system. This saves much time, and is an easy reference when repeating the testing upon future occasions; for where buildings contain a large number of rooms and are of several stories in height, it becomes wearisome to measure the length, breadth, and height of each room, and work out the cubical extents, at the time of taking and working out the readings of the instrument. All attention is required when using the anemometer. Not only has the operator to look after his note book and instrument, but he has to time the reading with absolute accuracy; for, in making a minute test, if through carelessness five seconds short is timed in one room, and five seconds be added to the exact time in the next room tested (which may possibly be of the same cubical extent), then this gives a difference of ten seconds in time, and for a minute test, this means also a difference in calculation of about $\frac{1}{6}$ in the volume of the air delivered; so that, although the two rooms may possibly have an equal change of air per hour, the testing would show that one room had $\frac{1}{6}$ more air being propelled into it than the other. More care is required in accurately timing the test than in reading the anemometer afterwards, and less inaccuracy is liable to creep in with the reading of the instrument than with exactly timing the test. A watch with a large second hand is the most useful, and if a stop watch, it has a further advantage. The anemometer should always have the large hand at zero before starting the test, and if the number of hundreds be noted in the book, inaccuracies, with ordinary care, seem hardly possible.

As the velocity of the air delivered through the inlet grating is greatest at the top of the opening, and the minimum about four inches from the bottom, it is necessary when testing, in order to obtain a fair average of the velocity, to continually move the anemometer about, from the top to the bottom of the opening, in a series of V's, through the whole length of the aperture, and then crossing the opening from the opposite corners. This, if carefully done, will give a fair average of the velocity of the air. As previously explained, no air is propelled into the rooms from the lower four inches of the opening, but the anemometer must be passed over this lower part to obtain the average.

Were the anemometer not brought below the line of the minimum flow of air, in ascertaining the average, the total velocity thus obtained could only be multiplied by the area so affected; and the difficulty in practice would be to find out the exact line where the air ceases to be effective.

It is much simpler, and less liable to error, to average the velocity over the whole area of the opening, and multiply the average velocity so obtained by the total area of the inlet.

Where an inlet opening is covered with wirework, this obstruction, although slight, must play its part in the calculations. Suppose the wire to be of 2-inch mesh and $\frac{1}{16}$ of an inch in thickness, then there would be 18 strands of $\frac{1}{16}$-inch metal to each foot super, and $18 \times \frac{1}{16} = 1\frac{1}{8} \times 1$ foot $= 13\frac{1}{2}$ inches area of wire in 144 square inches, which is found to be equal to nearly 10 per cent.; so that 10 per cent. must be deducted from the total area of the inlet opening when ascertaining the true and effective area or free passage for the propelled air.

It is only necessary to detail the operation required for a single test, as no matter what number of rooms require testing, the principle is only one of multiplication.

Let it be required to know the following, viz.:—the velocity of the air being delivered, the number of cubic feet supplied per person per hour, the total change of air taking place in the room per hour, and the required velocity per minute in order to supply a given number of changes of air per hour.

In the first place, to arrive at the velocity of air per minute: the anemometer (with the lever switched off and the large finger of the index at zero) is placed close to the face of the inlet grating and at about two-thirds of the height of same, and when the propeller of the instrument has attained its normal velocity (about ten seconds is required) the lever is switched on so that the dial commences to register; at the precise moment that the lever is switched on, the time should be fixed by the second hand upon the watch, the anemometer must be moved slowly, but evenly, over the whole surface of the inlet opening, keeping it close against the wirework, and as soon as the sixty seconds has elapsed, the lever of the anemometer is switched off.

Suppose the index shows 300, then as 30 has to be added for friction, the total velocity will be 330 feet per minute or 5½ feet per second.

If greater accuracy is required, then a five minutes' test should be taken, in which case the reading may be 1,500 feet, but 5 × 30 feet or 150 feet has to be added for friction, making a total of 1,650 feet velocity per five minutes, or 330 feet velocity per minute, or 5½ feet per second as before.

In the second case, to ascertain the number of cubic feet supplied per person per hour:—

Suppose the velocity be 330 feet per minute, and assume a school classroom accommodating 60 scholars, and the area of the inlet opening is found to be 3 ft. 4½ × 2 ft. covered with $\frac{1}{16}$ wire 2-in. mesh, then the calculation will be as follows :—

| | ft. | in. |
|---|---|---|
| Length of inlet opening ... ... ... | 3 | 4½ |
| Height of inlet opening ... ... ... | 2 | 0 |
| Area of inlet opening ... ... | 6 | 9 |
| Deduction for wire covering 10 per cent. | | 8 |
| Available area ... ... ... | 6 | 1 |

Velocity of air per foot per minute = 330
Amount of air impelled per minute = 330 × 6 ft. 1 in.
= 2,007 ft.
Amount of air impelled per hour = 2,007 ft. × 60
= 120,420 ft.
Number of occupants ... ... = 60
Amount of air per head per hour $= \frac{120{,}420 \text{ ft.}}{60} = 2{,}007$

Therefore 2,007 cubic feet of air per person per hour would be provided.

It is required, thirdly, to ascertain the number of times the air is changed in the room per hour :—

Take the previous case and assume a room 25 ft. × 24 ft. × 14 ft. high.

Then the calculations would be as follows :—

Cubical extent of room = 25 ft. × 24 ft. × 14 ft. = 8,400 ft.
Total quantity of air delivered per hour (as previously ascertained) = 120,420 ft.
Number of changes per hour $= \frac{120{,}420}{8{,}400} = 14{\cdot}3$

The air is therefore changed 14·3 times every hour.

Lastly, it is required to know the velocity per minute, in order to supply a given number of changes per hour.

Presume it is required to change the air in a room 11 times per hour, and that the room contains

8,400 cubic feet, and the inlet opening is 3 ft. 4½ in. long and 2 ft. high.

We proceed as follows:—

Cubical extent of room = 8,400 ft.

Number of changes required per hour = 11

Total air required to effect the prescribed change per hour = 8,400 × 11 = 92,400

Total air required to effect the prescribed change per minute = $\frac{92,400}{60}$ = 1,540.

Total available area of inlet opening as previously ascertained = 6 ft. 1 in. = 6·083 ft.

Velocity required per minute = $\frac{1,540}{6·083}$ = 253 ft.

The velocity required would be 253 ft. per minute, or 4·21 ft. per second.

Upon the basis of the four previous examples, any calculations may be made as required.

Should there be two or more inlet openings supplied to one room, all the results must be added together in order to arrive at the total change of air per hour, or the total quantity of air delivered per person per hour.

In a similar manner, the velocity or volume of air may be ascertained, either at the intake opening, or in the ducts and flues.

It sometimes happens that it is necessary to know the total number of cubic feet of air which is being propelled into a building. This can be ascertained in one operation by testing, either at the intake opening or in the main duct, before the air commences to be delivered into the subsidiary ducts. This is much more expeditious than testing the whole of the rooms and adding the results together in order to ascertain the total, and is much less liable to inaccuracies.

# CHAPTER XIV

## *CONCLUSION*

A DESCRIPTION of Plenum Ventilation, having been presented, it is felt that the strongest argument that can be written in favour of propulsion has been adduced. Indeed there can be but one more cogent, and that is experience. Most, if not all, whose lot it is to spend much of their time in a building, operated upon by a successful Plenum Installation, will testify to benefits received, both in health and in personal comfort.

This being so, the public generally, and the members of the architectural profession in particular, as the natural guardians of the public welfare in such matters, owe a debt of gratitude to those who have invented and improved on the methods of mechanical ventilation until it has reached its present-day stage of excellence. Theoretical science has done much towards this result, but still more is due to practical experiment. It will be readily conceded that to experiment with a system of propulsion is a hazardous and costly means of obtaining practical knowledge, even with a prior acquaintance with all the sciences involved. Much is due therefore to the pluck and enterprise of the pioneers of this modern method of ventilation, and though it would be absurd to claim that they were altogether actuated by unselfish and philanthropic motives, yet their invention has conferred a boon on humanity, the benefits of which may not be estimated at their true worth by the majority for many years to come.

To individualise would be invidious, and for this reason all mention of the particular modifications of the system practised by the respective engineers, has been purposely avoided, as far as is compatible with an explanation of Ventilation by Propulsion as an integral system.

Nevertheless, the fact that such differences exist, must not be entirely ignored. They have their merits, and perhaps, in some instances, their demerits. It must be remembered that these modifications are all products of expert knowledge and skill, and the reason of their existence can be more or less logically supported, by their respective inventors, from admitted scientific facts.

That the opinions of the experts differ, in no wise proves that any one of their individual methods is not advocated by its inventor in all good faith; but it is one of the disadvantages of the existing state of things, that, since the expert is at the same time the contractor, he naturally, from business reasons, does all in his power to promote the general adoption of his mode in preference to any others.

But, however honest the intentions of the experts, their differences necessarily present a problem to the architect who contemplates a Plenum Installation. If the methods, and their attendant results vary, some must naturally be more successful than others. This is not only logical, but is evident from practical observation. And since the acknowledged experts in the science are themselves interested parties, the question arises, who is to say what particular engineer adopts the methods attended by the most favourable net results?

Herein, the architect must decide for himself. It is unnecessary to say that much depends upon his decision, and that accordingly as he selects wisely or unwisely, so in a great measure will the installation be effective.

It is to the interest of the various engineers to supply him with all special information ; and, as far as lies in their power, to afford him opportunities of inspecting their previously installed systems, and of testing the general results for himself. Indeed, in this respect, a little observation of practical working is worth a deal of intricate theory. This is where the expert and the layman meet on a common plane.

The architect is advised to take the utmost advantage of his opportunities to inspect schemes, noting the details as well as the degree of success of the respective installations. He should, where possible, obtain information as to the cost of maintenance also, and set this against the net result.

Should the first installation the architect visits be not altogether up to his ideals and expectations, he should remember the differences existing, and should reserve his judgment until he has seen more examples, rather than form an adverse opinion of propulsion generally, upon the evidence of one scheme.

In no case must he expect to find perfection. All that can be claimed for the new system is that it is an improvement on the old—a very great improvement—and that is all. Were it otherwise—if with the advent of this new mode, finality had been reached, such modifications and differences of detail as referred to, would no longer exist,—one method and only one method would be universally adopted, and that would be the perfect one.

It is necessary then, not only to seek points wherein a scheme excels, but to note in what particular one case compares unfavourably with others; for, although no installation can be said to be perfect, yet, on the other hand, few, if any, are entirely lacking in commendable qualities. It is the business of the architect, by a system of comparison, to note these variations of effect, whether advantageous or otherwise, and then to trace them back to their respective causes. In this work he can generally count on the assistance of the authors of the various schemes; for, naturally an engineer is ever ready to explain, in the minutest detail, the peculiarities wherein his method possesses a superiority over others.

In this way, the architect will soon discriminate between those modifications of the Plenum System, which tend, or do not tend, towards its perfection; and, with the assistance of his expert adviser, by a wise selection of what is best (provided always that the selected details are compatible) he will arrive at a combination which cannot fail to be satisfactory when executed. Not only will he be thereby serving his clients and himself by acquiring a successful installation for his building; but will be helping forward the science of ventilation in a manner that no expert can adopt; for it is no disparagement to say that the engineer, who has an honest faith in his own inventions, and, as a business man, exploits them to his best abilities, must in the nature of things become somewhat biassed in his judgment on the merits and demerits of the various expedients employed.

On his tour of inspection, the architect will probably discover several instances where the whole scheme could have been made far more effective, had certain modifications been made at the time of installing, which would have entailed but a small extra on the initial cost.

Unfortunately, it is usual to give the Plenum contractor *carte blanche* as regards the carrying out of the work. He, as a business man, submits such an estimate as will leave no margin, save his legitimate profits. The terms of his contract contain very little of a binding nature as to the manner of executing the work, the merits of which is judged by the results attained in terms of cubic feet of air per hour. The consequence is, in carrying out his contract, the engineer is compelled to "cut things fine" often eventually, much to the inconvenience of the occupants of the building, or to the additional cost of maintenance. For instance, it often happens that an engine, of say, six brake power is provided, where for proper and economical working, one of eight brake power should have been supplied. Equally common is it to find that the propellers are so small, that an abnormal speed has to be maintained in order to effect the required rate of atmospheric change, and in consequence they become objectionably noisy.

Such imperfections, could have been obviated in the first place at a comparatively small extra cost, whereas after the completion of the work the expense of rectifying the defects is prohibitive.

Many of the indiscretions committed in the design of propulsion schemes, though not so irreparable are equally objectionable. In a great number of Plenum Systems a monstrous waste of water is constantly taking place, which could have been, and could now be, obviated, were sufficient tank accommodation supplied in order to cool the water from the engine, before it is returned to the cylinder, instead of wasting the whole of the water passing through the engine.

Such imperfections as these are neither due to ignorance nor carelessness on the part of the engineer. They are the direct outcome of the prevailing system under which propulsion work is contracted for. It is not to the advantage of the contractor thus to cut down initial cost to the detriment of the installation, and when estimating and contracting is done, under an architect possessing some technical knowledge of the work, there will no longer exist any cause for such evident false economy.

The architect will be wise to enter into relationship with the ventilation expert during the early stages of his planning, for although the positions of the ducts and flues are matters quite subservient to the general questions of design, yet by a little consideration, some expense and considerable inconvenience may be averted without detriment to the plan.

The work of the architect and that of the engineer should be mutual as far as the technical knowledge of the former will allow. The architect should see that the drawings and the explanation of them (which should be somewhat in the form of a specification) are clear and concise, both from a technical and a legal point of view. Only in this way can the business be transacted on a sound basis, and the architect know precisely what is estimated for, and be in a position to see that the contract is duly carried out.

The architect will find that his responsibility does not end upon the completion of the work. However he may protect himself legally, his clients will continue to hold him morally responsible for anything in connection with the installation which might not prove to be just as it should. Nor is this all ; he will probably find himself in some way responsible for defects which have no existence save in the imaginations of the occupants of the building. Impossible draughts and "bad air" are the complaints most familiar to the architect who has superintended an installation. This may be accounted for to a great extent by the fact, that with most people, ventilation by propulsion is something quite new, and to have all the windows hermetically sealed, is diametrically opposed to the preconceived notions of the general fitness of things; while air "pumped up from somewhere downstairs through holes in the walls," is something to be regarded with suspicion.

But it must not be concluded that all complaints, however absurd, are groundless. Very often, a slight defect, usually in the working of the apparatus, is revealed, on investigation, although the true cause of the annoyance is not specified in the complaint.

As a rule, the attendant in charge is at fault. Either through carelessness or ignorance, a damper is closed when it should be opened, or the water is turned off and things immediately go awry.*

But where the attendant most often transgresses is in connection with cleanliness. Insufficient use of the hose, or its absence entirely, is as often as not the cause of most trouble. Filth accumulates in the ducts, on the batteries, and elsewhere, and instead of being washed away on the first opportunity, it is allowed to remain until it is carried with the air into the rooms. Then letters are written complaining of the "bad air."

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* A case was noted where everything had been left in the hands of the man in charge, and upon a surprise visit being made by the writer, it was found that no water had been used upon the so-called filtering and humidifying screens for a period of three months.

The architect would do well to pay occasional visits in order to see that all the parts of the systems are flushed down and kept absolutely clean. In short, he should take nothing for granted, and leave nothing to the sole responsibility of the mechanic engaged to work the installation, for where this is done, failure is too often the result.

Superior supervision and occasional surprise visits at irregular intervals are essential to ensure the proper and efficient working of a Plenum Installation ; but if the architect pay some regard to this matter, there can be little doubt that, during the period of maintenance, the scheme will overcome all prejudice by its own merits, and give perfect satisfaction to those concerned, so that, at the end of that time, the architect, with a clear conscience, may sign the final certificate.

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